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5 May 2004

William Wehrum
USEPA Headquarters
Ariel Rios Building
1200 Pennsylvania Avenue, N. W.
Washington, DC 20460

Rec'd
8P - AR
MAY

Dear Mr. Wehrum:

Pursuant to a Memorandum of Understanding between the U.S. Environmental Protection Agency and the State of North Dakota, we have completed "A proposed alternative air quality modeling protocol to examine the status of attainment of PSD Class I increments." A copy is enclosed.

Pursuant to Section III.1 of the Memorandum of Understanding, EPA has orally accepted the enclosed protocol. The protocol is based upon discussions between EPA and the Department that concluded on 28 April 2004. In addition, the Department plans to obtain information that quantifies correspondence between wind data derived from RUC-2 data and observed wind data

The Department will proceed to execute this protocol. Although the process of the MOU is ahead of schedule, the Department intends to complete execution of the protocol within the 75 day modeling time line provided by the MOU. Periodically, the Department will inform EPA of its progress.

We have appreciated EPA's assistance in addressing the important air quality issues. We believe our discussions and the protocol have resulted in the positive advancement of air quality modeling science and technology used to protect our most pristine regions.

Sincerely,

L. David Glatt, Chief
Environmental Health Section

enc. as noted
cc: Governor John Hoeven
Bill Harnett, EPA, Research Triangle Park, NC
Richard Long, EPA Region VIII
Lyle Witham, Office of Attorney General
Terry O'Clair, Division of Air Quality

A proposed alternative air quality modeling protocol

to examine the status of attainment of PSD Class I increments.

FINAL

reflecting U.S. EPA comment as well as final editing

April 30, 2004

Prepared by
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Executive summary.

A Memorandum of Understanding between the State of North Dakota (hereafter State) and the United States Environmental Protection Agency (EPA) describes agreed-upon elements of an air quality modeling protocol when implementing Prevention of Significant Deterioration within the state under the federal Clean Air Act. This document provides many input and output details and describes some data processing methods for implementation of these elements of the modeling protocol.

Overview of elements for an alternative CALMET and CALPUFF modeling protocol.

EPA and the State agreed that the State may:	Summary of alternative implementation action:
Use recent versions of CALMET and CALPUFF models.	Values and settings in input control files for CALMET and CALPUFF that establish the modeling domain and that govern model computations are specified.
Model the baseline emission inventory and the current emission inventory to determine estimated baseline concentrations and current concentrations, respectively, for calculating any change in air quality since the baseline and to assist in examining correspondence between modeling and monitoring in any accuracy analysis.	Two sulfur dioxide source inventories have been created, one for the PSD baseline period and another for the current period. Results of modeling the current inventory will be compared to actual observed concentrations in model accuracy tests.
Use actual emissions data from years from a different time period other than the two years preceding the minor source baseline date when that time period (two years) is more representative of normal source operations.	The baseline period normally is the two years preceding the PSD minor source baseline date; however, analysis of production or operating data revealed that operations following that date were more representative of normal source operations for some power production sources and a charcoal briquette production plant.

EPA and the State agreed that the State may:	Summary of alternative implementation action:
Use sulfur dioxide emission factors based on recent continuous emission monitoring (CEM) data, and corresponding coal consumption and coal sulfur-content data, to establish emission factors for estimating baseline emissions.	Source-specific AP-42 emission factors were determined for the units of baseline power plants. These factors and baseline coal consumption coal sulfur-content data were used to determine baseline emissions.
Use actual emissions in emission estimation procedures for short-term time periods that are consistent with the CAA and promulgated EPA and North Dakota regulations.	The State's rates are actual emissions modified by source operating hours. The baseline rates for some power plants were calculated using source-specific emission factors, amounts of coal consumed during the two years of normal operations, and the sulfur content of that coal. The current rates for these plants were calculated from CEM data.
Use five (5) years of mesoscale meteorological data such as National Weather Service upper air and hourly surface data or, alternatively, three (3) years of prognostic meteorological model (MM) data suitable for CALMET, such as advanced MM5 or Rapid Update Cycle (RUC) data.	The State has six (6) years, 1990 through 1994 and 2000, of National Weather Service (NWS) upper air and surface meteorological data. NWS upper air and surface data for years 2001 and 2002 will be assembled. The State also has three (3) years, 2000–2002, of hourly RUC2[d] derived from RUC-2 data
Use air quality monitoring data to guide choices, when appropriate, for the modeling protocol so that modeling results achieve reasonable agreement with that data. The background sulfur dioxide concentration is a critical component of model accuracy analyses.	Model accuracy analyses will be completed. A background concentration for sulfur dioxide in the State's PSD Class I areas – during weather events causal of the higher ambient concentrations due to sources in the modeling domain – of 1.5 micrograms per cubic meter will be used for 3-hour and 24-hour model accuracy analyses.

The modeling protocol can be described as a sequence of interdependent actions. A summary of the modeling protocol is shown in the chart below. Details for each step of the protocol, except preparation of the meteorological and geophysical data and set-up of sensitivity analyses, are provided.

Summary outline of the modeling protocol.

After completing steps 1 and 2, complete step 3 if needed. Repeat steps 1 and 4 through 6 at right – for each of three years (2000, 2001, and 2002) of advanced prognostic mesoscale meteorological data, RUC2[d] data, with assimilated NWS hourly surface and twice-daily upper air meteorological data.	Step 1. Prepare: A) meteorological data and geophysical data, and B) CALMET control-file input data and CALPUFF control-file input data.
	Step 2. Prepare: A) current (years 2000 and 2001) sulfur dioxide emissions inventory, and B) baseline sulfur dioxide emissions inventory.
	Step 3. Conduct model sensitivity analysis as appropriate, and adjust select control-file inputs if warranted.
	Step 4. A) Determine current concentrations for each of the PSD Class I areas (model the current sulfur dioxide emissions inventory with and without FLM CONAI sources). B) Determine the accuracy of model predicted concentrations by statistical comparison with monitored concentrations.
	Step 5. Determine baseline concentrations for each of the PSD Class I areas (model the baseline sulfur dioxide emissions inventory).
	Step 6. Compute and tabulate sulfur dioxide deterioration after PSD baseline with and without FLM CONAI sources: A) paired in space (each receptor) and in time. B) paired in space (each receptor) only.

FLM CONAI = Federal Land Manager Certification of No Adverse Impact

Introduction.

Brief background

Since 1999, the State has engaged in actions to ascertain whether the federal CAA's PSD Class I 24-hour increment for sulfur dioxide is exceeded and, if so, the amount of emitted sulfur dioxide that should be captured by controls so as to satisfy that increment. These actions dealt with several unique challenges.

It was the State's first review of the status of attainment of PSD sulfur dioxide increments that did not include a new source or source modification.

There is no existing EPA proven methodology for conducting this review either in rule or in EPA guidance.

There are no field monitoring data at the time of the PSD trigger date (6 January 1975) or the PSD minor source baseline date (19 December 1977) for western North Dakota, including the PSD Class I areas. Monitoring data are available from about 1980. The results of a draft 1999 modeling assessment of deterioration since PSD baseline were not in harmony with monitoring data.

The technology and protocol for mesoscale air quality modeling has been, and is, in flux; specifically, advances are occurring in meteorological drivers for the CALPUFF model, and comprehensive inventories of emitted sulfur dioxide were first compiled three years ago.

FLM certifications of no adverse impact were granted to several facilities in North Dakota, two of which are operating at this time. Ambient concentrations of sulfur dioxide in the North Unit of the Theodore Roosevelt National Park (TRNP), a PSD Class I area, have declined over the past twenty years.

Sulfur dioxide monitoring data from locations in Class I areas reflect all emitted sulfur dioxide, including any deterioration since PSD benchmark (baseline) years. The objective of this alternate modeling protocol is to: first, simulate current concentrations that are in reasonable harmony with available monitoring data; second, simulate baseline concentrations in a consistent manner; and third, calculate deterioration as the difference between current and baseline concentrations.

North Dakota has a long-standing history of administrating provisions of the CAA under federal program primacy granted by EPA to the State. More than twenty-two years ago, North Dakota was a leader in establishing a modeling protocol for assessing compliance of proposed new sources with PSD Class I increments. The modeling protocol for mesoscale domains includes two stages of models; a

meteorological model that establishes the geographic and atmospheric domain, which is CALMET, and a pollutant transport and dispersion model, which is CALPUFF.

Document scope

Data inputs for air quality modeling include numerous input variables having a variety of purpose for computer execution of the models and for prediction of ambient concentrations of an emitted pollutant such as sulfur dioxide. The predicted concentrations can be more sensitive to the settings or values of some variables than settings or values of other variables. Some information such as weather data and terrain data must be pre-processed prior to use by the models. Conclusions regarding amounts of air quality deterioration depend on data output compilation methods. This document provides a modeling protocol as an alternative to prior protocols. It describes methods or lists settings and values related to:

a. meteorological data inputs,
b. CALMET control-file inputs,
c. CALPUFF control-file inputs,
d. current-period and baseline-period inventories of sources that emit sulfur dioxide, including emission rates,
e. the role of model accuracy tests, including background concentration for such tests, and
f. gauging deterioration of ambient sulfur dioxide concentrations after PSD baseline.

This document does not address all details of an alternative modeling protocol; the remaining details, such as preparation of terrain elevation, land use and precipitation data, will follow a May 2003 State Department of Health modeling protocol. Prominent topographic features are the Little Missouri River, the Missouri River and Lake Sakakawea.

[Note. The words predict, prediction, etc., are used throughout this document in past context, which relates to assessment of anticipated air quality impacts of proposed new sources as contributing impacts to emissions of existing, operating sources. In a periodic review, there is no proposed new source, and modeling is used to simulate the air quality impacts of existing sources.]

Basis for an alternative modeling protocol

Over the last 25 years, air quality models have been used to predict expected ground level concentrations due to source emitted pollutants. The models have advanced from crude representations of transport winds and dispersion; the advancements resulted in

improved model skill and, thus, less need for conservative assumptions so as to protect health or welfare. The State has adopted upgrades of models and modeling methods throughout the years. On occasion, the State has made contributions to those methods.

The State's protocol for use of CALMET and CALPUFF anchors to several sources of information, such as instruction provided by the CAA, PSD rules and EPA interpretive preambles and decisions by courts. In addition, IWAQM guidance, EPA guidance, FLM FLAG guidance, model user manuals and results of model sensitivity tests using input alternates may also apply.

In the past, tests of the sensitivity of CALMET and CALPUFF output to values or settings of some input control variables were completed, and some values or settings were chosen based upon test results. Some tests did not include monitoring data, and others did. Selection of model control inputs to tune, or calibrate, a model may improve agreement between model calculated data and observational data, but such choices may not improve the science of the model. Additional sensitivity tests, or diagnostic tests, may be conducted if warranted; these tests will examine the technical performance of model calculation methods and algorithms.

The second highest 24-hour ambient concentrations among all days in the South Unit of TRNP were: for year 2000, 9.39 ug/m3; 2001, 8.81 ug/m3; and 2002, 8.30 ug/m3.

The State has ambient sulfur dioxide concentration data obtained with field monitors. These data are the air quality consequence of the transport, dispersion and depletion of the sulfur dioxide emitted by operating sources. Model protocol accuracy should be quantified and reported when monitoring data are available. (See section 10.1.3 of 40 CFR 51, Appendix W.) Model accuracy results that indicate over prediction of concentrations soften concern that model inputs and results are adequately conservative so as to protect health or welfare.

The State has used its monitoring data to test the accuracy of the CALMET and CALPUFF models. Past accuracy tests demonstrate that the duo over predict the largest monitored concentrations, regardless of time of occurrence of those concentrations during the year (unpaired in time, but paired at place). However, the duo has no skill in predicting concentrations that correspond day-to-day throughout the year with monitored concentrations (paired in time as well as at place). (See also paragraph b, section 10.1.2 of 40 CFR 51, Appendix W.)

Treatment of sources granted CONAI

Prior to 2002, several proposed sources were granted FLM certifications of no-adverse impact (CONAI); two of these sources are currently operating. (See Appendix C.) Results of assessments of deterioration of ambient sulfur dioxide concentrations will be compiled without and with contributions due to the sulfur dioxide emissions of those two sources. Provisions of the CAA and PSD rules will govern interpretation of results. The FLM FLAG guidance also may apply.

CALMET control file inputs.

Meteorological data

Within the last two years, the State received three advanced hourly meteorological model data sets at 10 kilometer resolution for input to the CALMET model. The three data sets include years 2000, 2001 and 2002. The data sets were prepared by WindLogics, Inc., (formerly Software Solutions and Environmental Services Company). WindLogics captured and archived NOAA's Rapid Update Cycle version 2 (RUC-2) short-term forecast model data, which has a 40 kilometer horizontal resolution and over 40 layers of data in the vertical dimension. Because the 40 kilometer horizontal resolution is typically insufficient in coastal and mountainous regions, WindLogics adapted the ARPS Data Assimilation System (ADAS) to assimilate hourly surface weather data and terrain data with the RUC-2 data and to extrapolate these data to a 10 kilometer horizontal resolution in a format compatible with the MM5 data ingest capability of CALMET. For this protocol, the resulting data are labeled $RUC2^d$. [Note. For information on RUC and other large scale meteorological data sets, see Attachment 1 and http://maps.fsl.noaa.gov/ , http://www.nws.noaa.gov/om/tpb/448body.htm and http://www.meted.ucar.edu/nwp/pcu2/rucvres2.htm. For information on ADAS, see http://www.caps.ou.edu/ADAS.html. For a description of the adaptation of RUC-2 for CALMET by WindLogics, see http://www.ssesco.com/Airquality.html and Attachment 2.]

EPA and IWAQM have promoted two-tier air quality assessment protocols. Tier one is less rigorous but provides conservative results. When results indicate compliance with standards, such as the NAAQS, no further analysis is pursued. However, when results indicate apparent non-compliance, a more robust and rigorous tier-two analysis is undertaken. In this context, the State will use the three years of $RUC2^d$ data, rather than five years of NWS twice-daily upper air and hourly surface meteorological data, to refine modeling assessments of air quality deterioration. No MM4 data will be used.

The State has six (6) years, 1990 through 1994 and 2000, of NWS twice-daily upper air and hourly surface meteorological data for an area that is larger than the modeling domain. The locations of stations where the data were collected during year 2000 are shown on an attached map. In addition, NWS mesoscale meteorological data for years 2001 and 2002 will be assembled. The data for years 2000, 2001 and 2002 will be used with $RUC2^d$ data in Step 2 CALMET wind field computations.

CALMET code revision

CALMET meteorological model version 5.2 will be used. CALMET extrapolates surface winds to upper layers in two steps. The CALMET code has been revised as shown in Appendix A for use only when applying NWS twice-daily upper air and hourly surface data without prognostic meteorological data so that surface data are not vertically extrapolated in Step 2 wind field calculations,

because Step 2 wind field computations do not use BIAS values that vertically dampen the influence of surface winds in calculation of upper air winds as do Step 1 computations. [Note. The software change applies only to application of CALMET on State modeling problems and only when using NWS twice-daily upper air and hourly surface data, and it may not be universally applicable.]

Control file inputs

Several CALMET control file inputs describe the geographic and atmospheric domain for air quality simulation modeling. The domain must spatially reflect locations of PSD Class I areas, locations of sources of sulfur dioxide emissions that impact ambient sulfur dioxide concentrations in those areas, and the weather that transports and disperses sulfur dioxide from those sources.

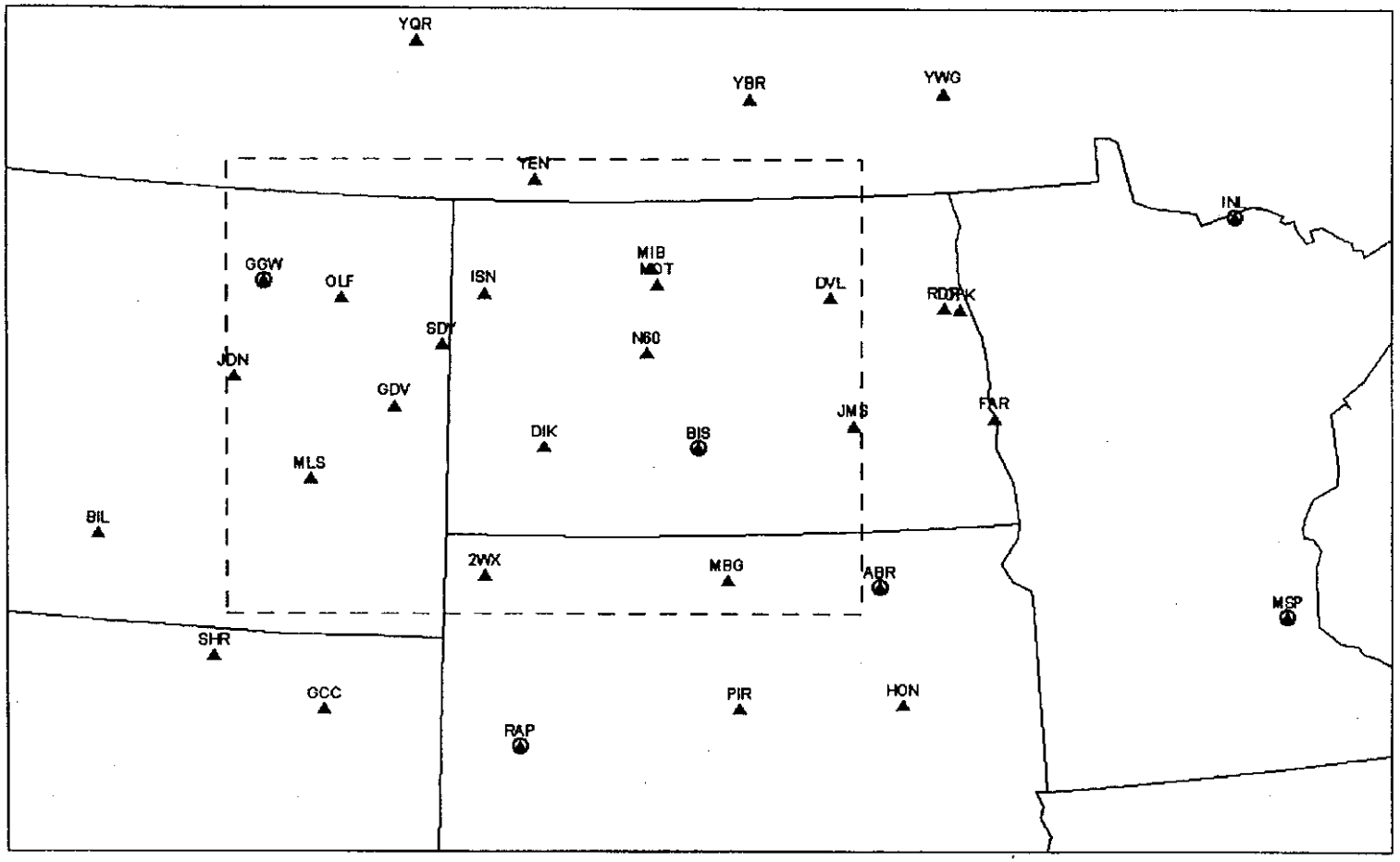
Control file inputs also govern use and interpretation of terrain data, weather data and other descriptors of the selected domain. An attached table shows those CALMET control-file inputs that are uniquely appropriate for the State's geographic and atmospheric modeling domain, as well as inputs for computation of gridded wind fields that govern transport of emitted sulfur dioxide. The dimensions of the modeling domain are 640 kilometers west-east and 460 kilometers south-north. Because this domain is large, a Lambert Conformal grid and Lambert Conformal Coordinates for locations of meteorological and precipitation stations will be used.

The right column in the attached table describes the alternative CALMET inputs when using RUC2[d] (shown as "R") data. A column in this table describes alternative CALMET inputs when using only NWS twice-daily upper air and hourly surface mesoscale meteorological data. Model protocol results can be sensitive to those control-file input variables that are color shaded. All other required CALMET control file inputs follow IWAQM recommended default values or settings.

The approximate heights above ground level at Bismarck for the 850, 700 and 500 millibar pressure altitudes of the standard atmosphere are, respectively, 500, 2,500 and 5,000 meters . The National Weather Service uses rawinsondes to twice-daily measure upper air winds at these and other pressure altitudes. In addition, the stack heights of sources, other than oil and gas production sources, range from 20 meters to 200 meters above ground level. Therefore, alternative values for variable ZFACE, which is the tops of twelve wind field layers, are set at 20, 50, 90, 140, 200, 270, 370, 500, 1000, 1700, 2500 and 4200 meters. The bottom of the lowest layer is 0 meters. The highest ZFACE level is 200 meters above the height of variable ZIMAX, which is the maximum over land mixing height. [1]

[1] The maximum mixing height of the upper Great Plains is 4,000 meters. (Holzworth, 1972. Mixing Heights, Wind Speeds, and Potential for Urban Air Pollution throughout the Contiguous United States. EPA Publication No. AP-101, Office of Air Programs.)

Twice-daily upper air and hourly surface meteorological stations for year 2000.



CALMET user defined and non-IWAQM control-file inputs.				
Variable	**Type**	**Description**	**Alternative w/o R**	**Alternative w R**
NUSTA	integer	number of upper air stations within and surrounding the modeling domain – may change from year to year	6	6
IBTZ	integer	base time zone (7 = Mountain Standard)	7	7
NX	integer	number of grid cells in X direction	128	213
NY	integer	number of grid cells in Y direction	92	153
NZ	integer	number of vertical layers	12	12
DGRIDKM	real	horizontal grid spacing (km)	5.	3.
XORIGKM	real	reference LCP (Lambert Conformal Projection) X coordinate of southwest grid cell (km)	-380.	-380.
YORIGKM	real	reference LCP Y coordinate of southwest grid cell (km)	140.	140.
XLAT0	real	latitude at southwest corner of grid cell 1,1 (deg.)	45.152	45.152
XLON0	real	longitude at southwest corner of grid cell 1,1 (deg.)	106.848	106.848
ZFACE	real array: NZ + 1	cell face heights (m)	0., 20., 50., 90., 140., 200., 270., 370., 500., 1000., 1700., 2500., 4200.	same as w/o R
LLCONF	logical: T = True	if T, use LCP map coordinates and rotate winds from true north to map north	T	T
XLAT1	real	latitude for 1st standard parallel for LCP (deg)	46.0 [1]	46.0 [1, 3]
XLAT2	real	latitude for 2nd standard parallel for LCP (deg)	48.5 [1]	48.5 [1, 3]

Variable	Type	Description	Alternative w/o R	Alternative w R
RLON0	real	reference longitude used in LCP rotation of input winds (deg)	102.0 [2]	102.0 [2,3]
RLAT0	real	origin latitude used in LCP rotation of input winds (deg)	44.0 [2]	44.0 [2,3]
NSSTA	integer	number of surface meteorological stations within and near the modeling domain – may change from year to year	32	32
NPSTA	integer	number of precipitation stations within and near the modeling domain – may change from year to year	89	89
IKINE	integer	if 0 (IWAQM default), kinematic effects (a wind field option) are not computed	0	0
IEXTRP	integer	extrapolate surface winds to upper layers: 1 = no extrapolation, 4 or -4 (IWAQM default) = use similarity theory	-4	-4
BIAS	real array: one value for each of NZ layers	layer-dependent biases modifying the weights of surface and upper air stations (-1. =<BIAS<=+1.): negative bias reduces weight given upper air data, positive bias reduces weight given surface data, zero bias leaves weights unchanged	Step 1 only: -1.0, -0.9, -0.7, -0.4, 0.0, 0.3, 0.7, 1.0, 1.0, 1.0, 1.0, 1.0	do not apply
IPROG	integer	if 0, gridded prognostic model field winds are used: if 14, use MM5.DAT file as initial guess field	0	14
LVARY	logical: T = True, F = False	if F (IWAQM default), interpolation of winds at a grid point does not include met station observations located beyond RMAX1 or RMAX2 or RMAX3	F	F
RMAX1	real	max. radius of influence over land in the surface layer (km)	200.	100.
RMAX2	real	max. radius of influence over land in layers aloft (km)	800.	200.
RMAX3	real	max. radius of influence over water (km)	800.	200.

Variable	Type	Description	Alternative w/o R	Alternative w R
TERRAD	real	radius of influence of terrain features (km)	16.	10.
R1	real	in the surface layer, the distance (km) from an observation station at which the wind observation and the first guess field are equally weighted	16.	10.
R2	real	in the upper layers, applied same as R1	46.	10.
ISURFT	integer	surface station number used for the surface temperature for the diagnostic wind field module	1 (Bismarck)	12
IUPT	integer	upper air station number used to compute the domain-scale temperature lapse rate for the diagnostic wind field module	1 (Bismarck)	1
ZUPWND	real array	bottom and top of layer through which the initial guess winds are computed (m)	1., 2500.	not used
ZIMAX	real	maximum over land mixing height (m)	4000.	4000.
ZIMAXW	real	maximum over water mixing height (m)	4000.	4000.
MNMDAV	integer	max. search distance (in grid cells, one cell = DGRIDKM) in spatial averaging of mixing heights & temperatures	6	7
ILEVZI	integer	layer of winds used in upwind averaging of mixing heights (no default specified in the model)	3	3

footnotes:

1 = The first standard parallel at 46 degrees latitude is north of, but near, the southern border of North Dakota; the second standard parallel at 48.5 is south of the northern border of the state; thus, providing a balanced inclusion of the modeling domain.

2 = The approximate center of the TRNP/power-plant region is 47.35 degrees latitude and 102 degrees longitude (the LCP map Y-axis parallels true North at RLON0).

3 = RUC2[d] was constructed suitable for CALMET ingest as MM5 with the center latitude at 47.35 degrees, the center longitude at 103 degrees, the first standard parallel at 47.34 degrees latitude and the second at 47.36 degrees.

CALPUFF control file inputs.

CALPUFF transport and dispersion model version 5.4 will be used. Several CALPUFF control file inputs govern calculation of atmospheric transport, dispersion and depletion of the sulfur dioxide emitted by the sources in the modeling domain and, thus, assessment of deterioration (or improvement) of ambient sulfur dioxide concentrations in the PSD Class I areas.

An attached table shows those CALPUFF control file inputs that are uniquely appropriate for the State's Class-I-area modeling domain established by CALMET. The right columns in this table describes the inputs for alternative use of CALPUFF. All other required CALPUFF control file inputs follow IWAQM recommended default values or settings. Because the modeling domain is large, a Lambert Conformal grid and Lambert Conformal Coordinates for locations of sources will be used.

Model protocol results can be sensitive to those control-file input variables that are color shaded in the attached table. In addition, the east end of the meteorological grid was truncated for plume computational domain (IECOMP), because plumes that first travel east and then circle west to PSD Class I areas could travel distances greater than 300 kilometers. The south and north sides of the meteorological grid were truncated for the computational domain, variables JBCOMP and JECOMP respectively, so as to reflect CALMET variables R1, R2 and MNMDAV. The west side of the meteorological grid was not truncated for the computational domain, variable IBCOMP, due to the sources located near the west end of the grid.

Input control variable IVEG selects one of three algorithms for calculation of surface canopy resistance, which is a component of dry deposition. During the months of April through September (Julian days 91 through 273 in tables attached to Appendix H), vegetation in central and western North Dakota likely is active and unstressed or stressed. During the remainder of the year, vegetation likely is inactive. The highest sulfur dioxide concentrations occur in nearly equal proportion during the two calender seasons. (See tables attached to Appendix H.)

Background ozone data will be assembled into an input file (OZONE.DAT) as hourly ozone concentrations throughout the year from monitoring stations located in the TRNP-SU, at rural Dunn Center, at rural Hannover and/or near Beulah. One file will be assembled for each year of modeled meteorological data. When background ozone data are missing, the default concentration will be the value of variable BCKO3.

CALPUFF user defined and non-IWAQM control-file inputs.				
Variable	**Type**	**Description**	**Alternative w/o R**	**Alternative w R**
IBCOMP	integer	southwest X-index of computational domain	1	1
JBCOMP	integer	southwest Y-index of computational domain	4	6
IECOMP	integer	northeast X-index of computational domain	122	201
JECOMP	integer	northeast Y-index of computational domain	89	148
MTRANS	integer	if 1 (IWAQM default), transitional plume rise modeled	1 for all sources	1 for all sources
MTIP	integer	if 1 (IWAQM default), stack tip down wash modeled	1 for all sources	1 for all sources
MSHEAR	integer	if 0 (IWAQM default), vertical wind shear above stack tip not modeled in plume rise	0 for all sources	0 for all sources
MSPLIT	integer	if 1, allows puff splitting; if 0 (IWAQM default), no puff splitting // set as 0 for all oil & gas production sources	1 (0 as noted)	1 (0 as noted)
MDISP	integer	if 2, horizontal and vertical dispersion coefficients calculated using micro meteorological variables	2	2
MPDF	integer	if 1, probability distribution function for vertical dispersion under convective conditions used	1	1
XLAT	real	reference latitude of the center of the modeling domain used in solar elevation angle calculations (deg)	47.3	47.3
XLONG	real	reference longitude of the center of the modeling domain (deg)	102.	102.
XTZ	real	reference time zone of the center of the modeling domain	7.	7.

Variable	Type	Description	Alternative w/o R	Alternative w R
LSAMP	logical; F = False T = True	if F (IWAQM default), an internally calculated array of gridded receptors is not used [may set to T for select sensitivity tests, boundaries of the array would include all state Class I areas]	F	F
IVEG	integer	if 2, vegetation in unirrigated areas is active and stressed (IWAQM default = 1)	2	2
MOZ	integer	if 1 (IWAQM default), use hourly ozone concentrations from OZONE.DAT file	1	1
BCKO3	real	default background ozone concentration (ppb)	30.	30.
BCKNH3	real	background ammonia concentration (ppb)	2.	2.
XSAMPEN	real	max. travel distance of puff (in grid units, one unit equals DGRIDKM) during one sampling step	0.6	1.0
XMAXZI	real	max. mixing height (m)	4000.	4000.
IRESPLIT	integer array	set to 1 for hour(s) of day when nocturnal shear occurs (e.g., nocturnal jet) and when split puffs are eligible to be split once again; all other hours set to 0	hours 00–04 and 19–23 = 1	hours 00–04 and 19–23 = 1
ROLDMAX	real	puff splitting allowed only when the ratio of last hour's mixing height to max. mixing height experienced by the puff is smaller than this value (IWAQM default = 0.25)	0.33	0.33
BDOWN	real	if 0, building down wash is not modeled	0.	0.
SIGMAYI	real	initial plume (puff) sigma-y at release from source (m) – set for each pollutant for each source; set to 0.0 (IWAQM default) for oil and gas production sources	1/4 the stack diameter	1/4 the stack diameter
NREC	integer	number of non-gridded receptors	104	104

Sulfur dioxide emission rates.

Sources within the modeling domain that emit sulfur dioxide are geographically dispersed across western North Dakota and eastern Montana. Only those sources located in the western one-half of North Dakota and major sources located in eastern Montana were included in emissions inventories. The sources include coal-fired electricity generating plants, a synthetic natural gas production plant, natural gas processing plants, oil refineries, a charcoal briquette production plant and oil and gas production sources.

Some sources were constructed prior to the PSD trigger date (6 January 1975); some of these sources were retired after the PSD minor source baseline date (19 December 1977), and others are still operating. Some sources were constructed and began operating after the PSD minor source baseline date. A map of these sources is attached, and date data for these sources are provided in Appendix C.

Two sulfur dioxide source inventories have been created; one for the PSD baseline period and another for the current period. Twenty-two years separate the PSD baseline period and the current period. Sources constructed and operating after PSD baseline do not contribute to PSD baseline-period ambient concentrations. Sources that were retired after the minor source baseline date do not contribute to current-period ambient concentrations.

The baseline period normally is the two years preceding the PSD minor source baseline date. However, analysis of annual production or operating data revealed that operations for years following that date were more representative of normal source operation for some power production sources and the charcoal briquette production plant. For example, annual utilization of rated heat input capacity of coal-fired combustion systems of power plants can be determined from amounts of coal burned and the heat value of that coal. (See Appendix D.)

The current period for sources is the two-year period preceding the date of concern; the two years are 2000 and 2001, except that only year 2000 will be used for oil and gas production sources. The baseline inventory includes more than 850 oil and gas production sources (flares and treaters), and the current inventory includes more than 550 of these sources. (See Appendix F.)

Some sources that are located within the modeling domain but not modeled contribute to the background sulfur dioxide concentration; these sources are oil and gas production sources in North Dakota located beyond 50 kilometers from Class I areas and oil and gas production sources having sulfur dioxide emission rates less than 0.001 gram per second. Other sources that are outside the domain also contribute to the background sulfur dioxide concentration; these sources are heating plants and commodity processing plants in eastern North Dakota, sources in central and western Montana, and sources in Minnesota, South Dakota and southern Saskatchewan.

Instruction for representation of rates of emitted sulfur dioxide is provided by PSD rules and by EPA regulations (interpretive preambles). Rates as actual emissions, which is a term defined in PSD rules, provide consistent and comparable rates among all sources, including oil and gas production sources, and between both time lines (baseline and current period).

The sulfur dioxide emission rate for lignite-fired boilers is a function of the amount of coal burned and the sulfur content of that coal, as well as any natural sulfur dioxide scrubbing agents in that coal and boiler performance. Rather than using the AP-42 emission factor of 30S for power plants, an emission factor was calculated for each unit of power plants that does not have a sulfur dioxide emission control system. (See Appendix E.) The factors are a mass-balanced calculation between annual emissions from recent continuous emissions monitoring (CEM) system data and corresponding coal consumption and coal sulfur-content data. The factors were then used to calculate baseline rates using baseline-period coal consumption and coal sulfur-content data.

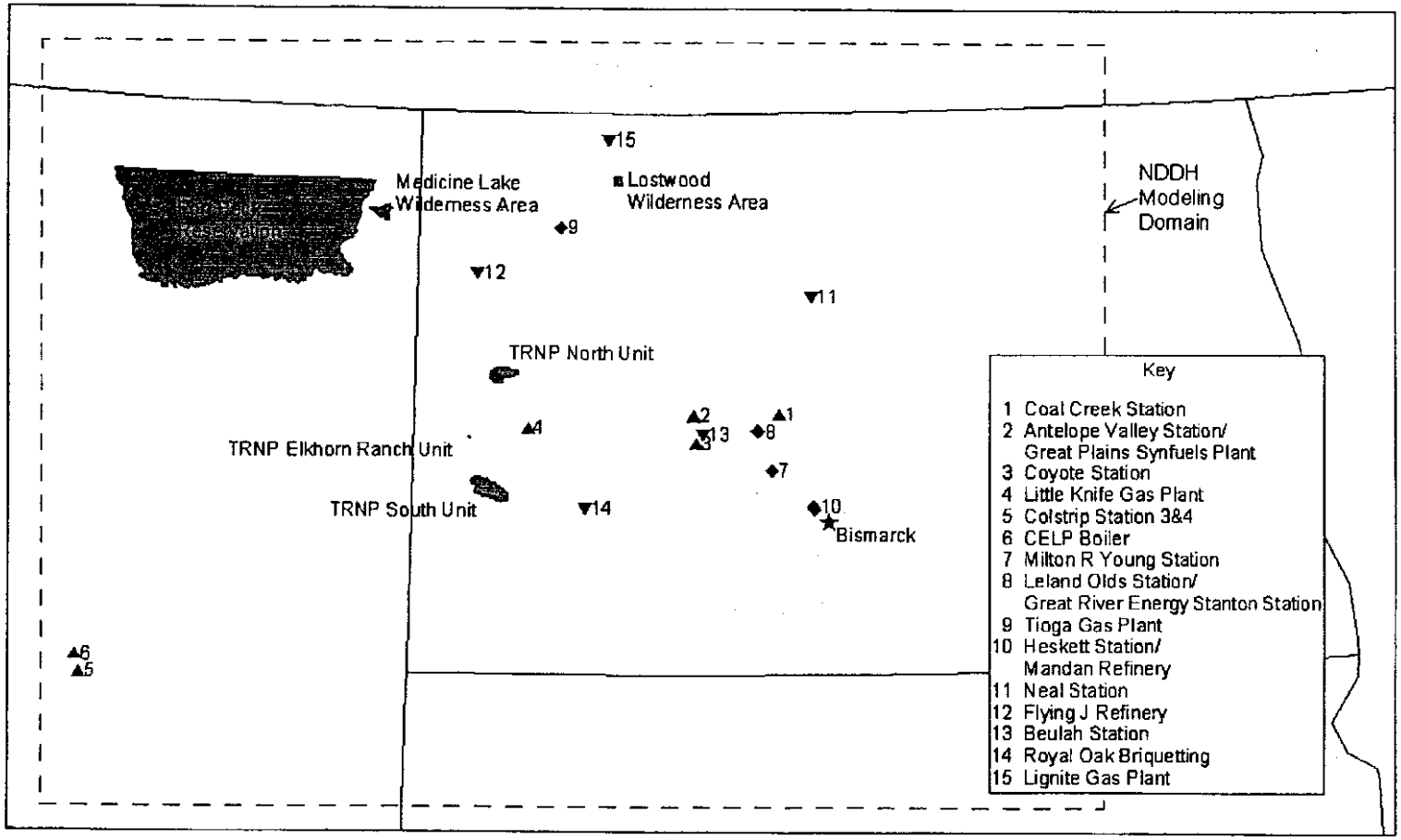
An attached table shows estimated baseline sulfur dioxide emission rates for all sources except oil and gas production sources. The sources of data for computation of baseline rates are shown, and the rates are actual emissions as annual emissions averaged over operating hours. The rates in the right column are based upon the sulfur content of coal consumed during the two-year period representing normal source operations. The right column in this table provides the baseline rates for alternative modeling.

Another attached table shows current-period sulfur dioxide emission rates for all sources, except oil and gas production sources. The sources of data for computation of rates are shown, and the rates are actual emissions computed as annual emissions averaged over operating hours. The right column in this table provides current-period rates for alternative modeling. The right column data include the two sources granted certifications of no-adverse impact by the Federal Land Manager.

Source locations in the modeling domain and source stack parameters are listed in Appendix D. These locations and parameters also are CALPUFF input data. Similar data for the numerous oil and gas production sources are not shown. Several sources have two or more points (e.g., stacks) of emitted sulfur dioxide. In these instances, stack data for each point are model inputs, except the same pair of coordinates for the location of each point of emitted sulfur dioxide at some retired sources has been used. Thus, emitted plumes at these sources as modeled are not horizontally separated as were the actual stacks.

[Note. The PSD minor source baseline date for sulfur dioxide for the Medicine Lake Wilderness Area (MLWA), a PSD Class I area in eastern Montana, is 26 March 1979, or about fifteen months later than such date for the North Dakota Class I areas. The baseline date for the Fort Peck Class I area follows 9 April 1984, when the non-federal re-designation became effective. Results of modeling with the sulfur dioxide emissions inventories provided by this protocol may trigger a refined analysis with emissions inventories reflecting baseline dates for these Montana areas.]

CALMET and CALPUFF modeling domain, including PSD Class I areas and sulfur dioxide source locations.



Sulfur dioxide emission rates of sources operating at the time of the PSD minor source baseline date.

Source	Unit	Basis	Baseline period	Ave. per.	Rate	Units	
Beulah Power Plant	1 & 2	e.i.r.	76 - 77	an.ave.	127.0	lb/op-hr	#
	3, 4 & 5	e.i.r.	76 - 77	an.ave.	203.6	lb/op-hr	#
Neal Station	1 & 2	e.i.r.	76 - 77	an.ave.	364.6	lb/op-hr	#
Royal Oak Briquetting	Boilers 1, 2 & 3	e.i.r.	78 - 79	an.ave.	220.8	lb/op-hr	
Plant	Carbonizer Furnaces	e.i.r.	78 - 79	an.ave.	1,124.8	lb/op-hr	#
Williston Refinery	All units	e.i.r.	76	an.ave.	51.7	lb/op-hr	
	Preflash Heater		76	an.ave.	7.1	lb/op-hr	
	Crude Heater		76	an.ave.	7.7	lb/op-hr	
	Thermal Cr. Heater		76	an.ave.	0.3	lb/op-hr	
	Charge Heater		76	an.ave.	0.1	lb/op-hr	
	Reformer Heater		76	an.ave.	0.5	lb/op-hr	
	Boiler 1		76	an.ave.	10.5	lb/op-hr	
	Boiler 2		76	an.ave.	10.5	lb/op-hr	
	Boiler 3		76	an.ave.	15.0	lb/op-hr	
R.M. Haskett Station	1	e.i.r.	76 - 77	an.ave.	415.8	lb/op-hr	#
	2	e.i.r.	76 - 77	an.ave.	969.9	lb/op-hr	#
Leland Olds Station	1	e.i.r.	77 - 78	an.ave.	3,609.8	lb/op-hr	#
	2	e.i.r.	77 - 78	an.ave.	7,312.4	lb/op-hr	#
M.R. Young Station	1	e.i.r.	78 - 79	an.ave.	4,357.0	lb/op-hr	#
	2	e.i.r.	78 - 79	an.ave.	4,726.5	lb/op-hr	+
Stanton Station	1	e.i.r.	78 - 79	an.ave.	2,220.1	lb/op-hr	#
Tioga Gas Plant	SRU Incinerator	e.i.r.	77	an.ave.	1,107.1	lb/op-hr	
Lignite Gas Plant	SRU Incinerator	e.i.r.	76 - 77	an.ave.	285.8	lb/op-hr	
Mandan Refinery	Boilers 1, 2 & 3	e.i.r.	76 - 77	an.ave.	622.6	lb/op-hr	
	Crude Furnace	e.i.r.	76 - 77	an.ave.	550.1	lb/op-hr	
	FCCU	e.i.r.	76 - 77	an.ave.	1,135.8	lb/op-hr	
	Alkylation Unit	e.i.r.	76 - 77	an.ave.	160.3	lb/op-hr	
	Ultraformer Furnaces	e.i.r.	76 - 77	an.ave.	15.3	lb/op-hr	

Total = 29,632.7

e.i.r. = annual emissions inventory reports
Ave. per. = averaging period
an.ave. = actual emissions during operating hours

lb/op-hr = pounds per operating hour
= rate based on source specific emission factor (Appendix E)
+ = rate based on annual heat input and permit allowed rate of 1.2 lbSO2/mBtu

Sulfur dioxide emission rates of sources operating during the current period (years 2000 and 2001).

Source	Unit	Basis	Current period	Ave. per.	Rate	Units	
R.M. Heskett Station	1	e.i.r., CEM	00 - 01	an.ave.	248.0	lb/op-hr	
	2	e.i.r., CEM	00 - 01	an.ave.	612.7	lb/op-hr	
Leland Olds Station	1	e.i.r., CEM	00 - 01	an.ave.	4,179.2	lb/op-hr	
	2	e.i.r., CEM	00 - 01	an.ave.	8,145.1	lb/op-hr	
M.R. Young Station	1	e.i.r., CEM	00 - 01	an.ave.	5,161.4	lb/op-hr	
	2	e.i.r., CEM	00 - 01	an.ave.	4,353.2	lb/op-hr	
Stanton Station	1 & 10	e.i.r., CEM	00 - 01	an.ave.	2,389.8	lb/op-hr	
Tioga Gas Plant	SRU Incinerator	CEM	00 - 01	an.ave.	300.6	lb/op-hr	
Lignite Gas Plant	SRU Incinerator	CEM	00 only	an.ave.	105.6	lb/op-hr	fn 1
Mandan Refinery	Boilers + Crude Furnace	e.i.r.	00 - 01	an.ave.	133.0	lb/op-hr	
	FCCU	e.i.r.	00 - 01	an.ave.	1,026.9	lb/op-hr	
	Alkylation Unit	e.i.r.	00 - 01	an.ave.	7.7	lb/op-hr	
	Ultraformer Furnaces	e.i.r.	00 - 01	an.ave.	15.9	lb/op-hr	
	SRU Incinerator	e.i.r.	00 - 01	an.ave.	45.3	lb/op-hr	
Coal Creek Station	1	CEM	00 - 01	an.ave	3,368.1	lb/op-hr	
	2	CEM	00 - 01	an.ave	2,972.8	lb/op-hr	
Antelope Valley Station	1	CEM	00 - 01	an.ave	1,590.8	lb/op-hr	
	2	CEM	00 - 01	an.ave	1,496.0	lb/op-hr	
Coyote Station	1	CEM	00 - 01	an.ave	3,955.4	lb/op-hr	
Grasslands Gas Plant	SRU Incinerator	CEM	00 - 01	an.ave	113.4	lb/op-hr	fn 2
Little Knife Gas Plant	SRU Incinerator	CEM	00 - 01	an.ave.	80.1	lb/op-hr	
Great Plains Synfuels	Main stack	CEM	00 - 01	an.ave.	1,094.4	lb/op-hr	
	Start-up flare	allowable	00 - 01	an.ave.	119.0	lb/op-hr	
	Main flare	e.i.r.	00 - 01	an.ave.	184.0	lb/op-hr	
	Back-up flare	allowable	00 - 01	an.ave.	78.0	lb/op-hr	
PPL Corp Colstrip	3	CEM	00 - 01	an.ave	742.9	lb/op-hr	
	4	CEM	00 - 01	an.ave	719.0	lb/op-hr	
CELP Colstrip		CEM	00 - 01	an.ave	419.8	lb/op-hr	

Total = 43,658.2

e.i.r. = annual emissions inventory reports
Ave. per. = averaging period
an.ave. = actual emissions during operating hours

lb/op-hr = pounds per operating hour
fn1 = began injecting sour gas during August 2002
fn2 = began injecting sour gas during March 2002

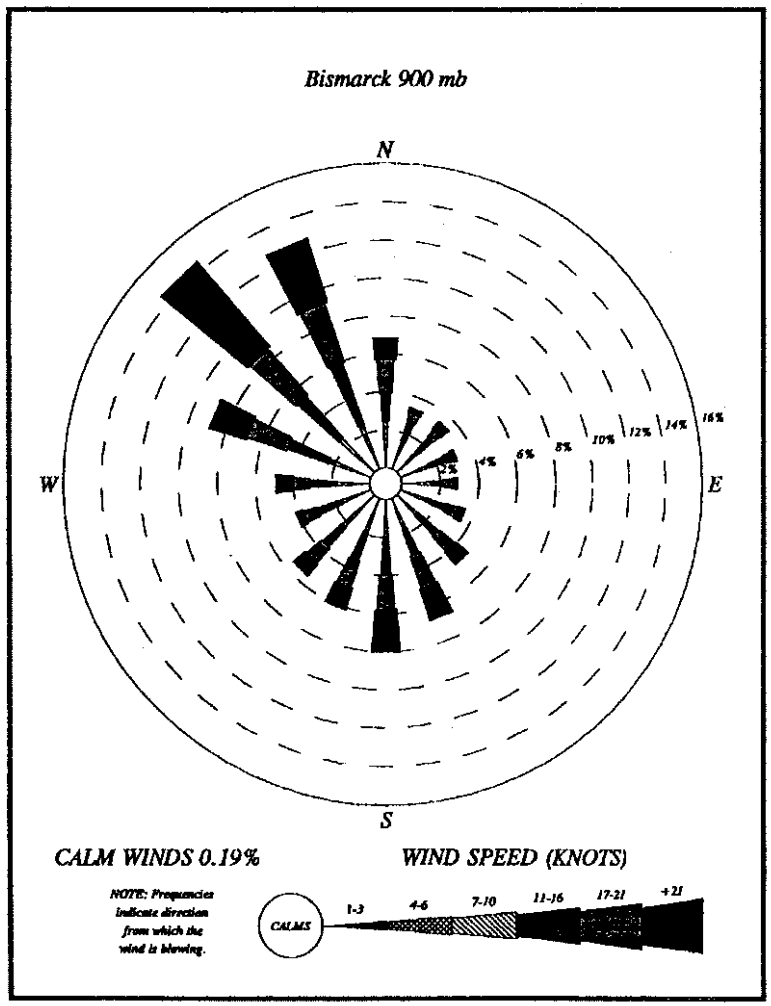
Background concentration and accuracy tests.

Orientation

Since some sources of emitted sulfur dioxide within the modeling domain and sources outside that domain are not included in model predicted concentrations, a background concentration representing those sources must be added to model predicted concentrations when comparing those concentrations with real concentrations obtained with monitors. (See Appendix B.)

Based upon monitoring data obtained in the North and South Units of the TRNP, the highest daily concentrations of sulfur dioxide usually occur during the months of November, December, January and February. (See tables attached to Appendix H.) Modeling indicates that utility sources, which are the larger emitters of sulfur dioxide, account for most of the largest predicted concentrations in TRNP.

The occurrences of the largest concentrations are due to transport winds originating east and southeast of the modeling domain. The wind rose shown at right for the 900-millibar pressure altitude at Bismarck demonstrates the low frequency of winds occurring from the east and southeast.



Probable background concentration

Magnitudes of background concentrations likely vary with origin of the boundary layer of the troposphere that migrates over western North Dakota. The boundary-layer pool of background sulfur dioxide likely includes a broad region east through south of the modeling domain where many sources are located. For

example, the background concentration could be determined with a sulfur dioxide monitor located in the vicinity of Wilton, North Dakota, that has the technology to detect low ambient concentrations in air prior to the transport of that air westward through coal county where sulfur dioxide is emitted. (See Appendices G and H.) The background concentration represents that sulfur dioxide in the air at the time when, and the places where, those sources in the emissions inventory emit sulfur dioxide. Any sources that are not in an emissions inventory contribute to the background concentration when their plumes of sulfur dioxide co-mingle with the plumes of sulfur dioxide from sources that are in the inventory. Monitoring instruments obtain data on total actual ambient sulfur dioxide; thus, monitoring data represent the sum of both contributions of sulfur dioxide.

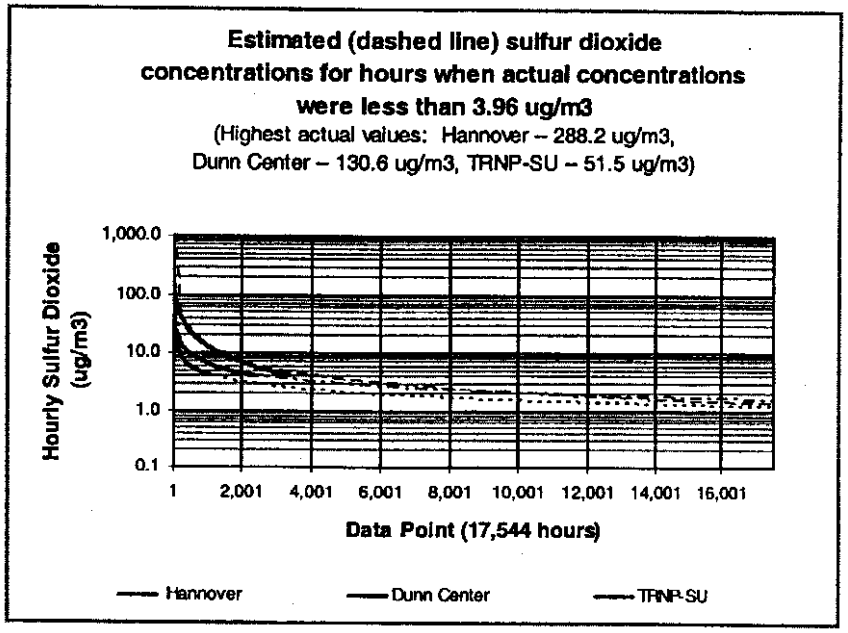
Some sources having stacks are located in eastern North Dakota and southern Minnesota. Another source, located in northeastern South Dakota, does not have sulfur dioxide emission control. Ground level emissions of sulfur dioxide occur from combustion of diesel fuel by non-agricultural and agricultural machinery, trucks and other vehicles. These ground level emissions occur throughout the state, but likely are more prominent in the eastern one-half of the state and regions east through south of there.

Near vertically uniform concentrations of stack emitted sulfur dioxide within the boundary layer occur downwind of sources at distances greater than 300 kilometers (about 190 miles). The ambient concentration at that distance due to a typical, uncontrolled source that emits about 4,000 pounds per hour would be about 1.9 parts per billion less depletion due to photochemical oxidation, deposition and convective vertical transport above the boundary layer. The photochemical oxidation rate for transformation of sulfur dioxide to sulfate varies from 0.5 percent per hour to 2 percent per hour; the lower rates occur during winter. One older study demonstrated that sulfur dioxide can be transported from the Ohio River Valley into southern Minnesota (study citation not available). The Minnesota Pollution Control Agency indicates that background sulfur dioxide levels in ambient air are as low as 1 part per billion. (See http://www.pca.state.mn.us/air/emissions/so2.html.) One part per billion equals 2.6 micrograms per cubic meter (ug/m3).

The Department of Health obtains actual observations of sulfur dioxide at several locations within North Dakota. (See Appendix H.) An estimate of the background concentration in the western region of the state can be calculated by extrapolation of the observations to hours when concentrations were less than the lower detection level of the monitoring instrument. The monitoring sites at rural Hannover and rural Dunn Center were chosen to estimate the background concentration because hourly concentrations greater than the instrument's lower detection limit occur more frequently there than at sites in Class I areas. For example, hourly concentrations greater than 1.5 parts per billion occurred during 19.4 percent of all hours during years 2000 and 2001 at the rural Hannover site, 13.8 percent of all hours at the rural Dunn Center site and 10.2 percent of all hours at the site located in the South Unit of TRNP.

The graph on the next page illustrates a power curve extrapolation of actual hourly sulfur dioxide data from the rural Hannover site, the rural Dunn Center site and the TRNP-South Unit site to probable concentrations less than 1.5 parts per billion (3.96 ug/m3) for

remaining hours of the two years. All hours of the actual sulfur dioxide data greater than 1.5 parts per billion were used regardless of wind direction. [2]



In summary, the background concentration for sulfur dioxide in the State's PSD Class I areas – during weather events causal of the higher Class-I-area ambient concentrations due to sources in the modeling domain – is likely in the range from 1 to 2 micrograms per cubic meter. A background concentration for sulfur dioxide of 1.5 micrograms per cubic meter will be used for 3-hour and 24-hour model accuracy analyses. [3]

Preliminary accuracy test results

People who develop models and who use models have an obligation to quantify correspondence between model predicted concentrations and actual observations of air quality. (For example, see section 10.1.3 of 40 CFR 51, Appendix W.) Thus, model accuracy tests will be completed.

Preliminary CALMET-CALPUFF accuracy tests of model predicted concentrations have been completed using past input values, settings and data. [4] Sulfur dioxide emission rates were based upon actual emissions that represent operating hours. Peak model

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[2] Monitor concentrations less than 1.5 parts per billion are unsuitable for estimating background concentrations. (See Appendix H.)

[3] Normally, the method for statistical averaging of hourly monitoring data for 3-hour or 24-hour averaging periods substitutes ½ of 1 part per billion for those hours when no sulfur dioxide was detected. In this case, ½ of 1 part per billion, or 2.62 ug/m3, is 1.31 ug/m3.

[4] In 1999, 2002 and 2003, the Department of Health completed and reported accuracy analyses related to PSD increment attainment; however, no background concentration was included in these analyses. Subsequently, the Department examined and reported accuracy tests to illustrate improved model accuracy using RUC2[d] data.

Preliminary ratios of model predicted concentrations to actual observations for year 2000.		
Background concentration (ug/m3)	Current-period sulfur dioxide inventory	
	with conventional meteorological data	with RUC2[d] meteorological data
2.0	1.52 *	1.18 *
* Numbers are an average of 25 ratios of the 25 highest predicted 24-hour concentrations to the respective 25 highest observed 24-hour concentrations. (See also paragraph b, section 10.1.2 of 40 CFR 51, Appendix W.)		

predicted concentrations at receptor number 38 were compared to peak monitored concentrations obtained from a site in the South Unit of the TRNP. This procedure is necessary as models are unable to predict the exact time as well as location where peak impacts will occur. Model predicted concentrations were larger than monitored concentrations. Results of these tests are shown in the table at left.

Guidance for representation of emission rates also is provided by EPA; some guidance recommends modeling short-term emission rates so as to protect PSD short-term increments. In historical modeling protocols, short-term emission rates corresponding to the averaging periods of short-term increments were used. Short-term rates often were expected peak rates, which may have had merit when sources generally, rather than seldom, simultaneously emit at such rates. (For example, see Appendix G.) But, the use of short-term rates conflicts with the definition for actual emissions in PSD rules. Because short-term rates are larger than rates as actual emissions during operating hours, use of short-term rates 24/7/52 would have resulted in ratios larger than shown in the table above.

Future accuracy tests [5]

Future accuracy tests of model predicted 24-hour sulfur dioxide concentrations will be completed using CALMET and CALPUFF control file inputs as provided in this protocol, meteorological data for years 2000 and 2001, current-period sulfur dioxide emission rates as provided in this protocol and the highest 25 daily averages of ambient monitoring data for both years. (See Appendix H.) The model predicted concentrations for these accuracy tests will be obtained at model receptors representing locations of monitors, and such receptors can be added to the list of Class I area receptors. Thus, no special modeling for accuracy tests is necessary.

Accuracy tests of model predicted 3-hour sulfur dioxide concentrations will be conducted in the same manner, but using the highest 3-hour averages of ambient monitoring data.

[5] No model performance tests, such as the execution efficiency of model software, are included in this alternate modeling protocol.

Deterioration of ambient sulfur dioxide in PSD Class I areas.

Model receptors

In air quality modeling, receptors are geographic points where the model predicts ambient sulfur dioxide concentrations due to source emitted sulfur dioxide. An attached map shows a two-kilometer Cartesian grid of receptors for each of three (3) PSD Class I areas in North Dakota. Additional receptors have been placed at the perimeter of two of the areas; these receptors are numbered 1xx. A fourth Class I area in North Dakota is small, and only one receptor is placed there. The attached map shows receptors at the southeast perimeter of two Class I areas in northeastern Montana. Alternative modeling will use these Class I area receptor locations.

Calculating and tabulating deterioration

Air quality deterioration subsequent to the PSD baseline is allowed by the CAA. The amounts of acceptable deterioration for sulfur dioxide were established as PSD primary and alternate increments. The benchmark, or reference point, for gauging deterioration (or improvement) of air quality in PSD Class I areas is the baseline concentration, which is defined in the CAA and PSD rules.

Under EPA's current method of gauging deterioration with the output of modeling source emission rate changes (increases or decreases) after PSD baseline, a baseline concentration is not determined for each short-term increment averaging period (3-hour or 24-hour). A consequence is an undetermined baseline concentration for each averaging period throughout the year at each receptor. And, reports then labeled the tabulated data as the "highest" and the "highest second-highest" (implied as concentration rather than the change in concentration) without acknowledging that the baseline concentration had not been determined.

Furthermore, this method of gauging deterioration lacks technical footing, because models have poor skill in predicting concentrations paired in time with monitored concentrations. For example, ". . . the models are reasonably reliable in estimating the magnitude of highest concentrations occurring sometime, somewhere within an area. . . . However, estimates of concentrations that occur at a specific time and site are poorly correlated with actually observed concentrations . . ." (See paragraph b, section 10.1.2 of 40 CFR 51, Appendix W.) This accuracy scenario is applicable to the current period and the PSD baseline model predicted [estimated] concentrations.

In the future, these problems of EPA's current method will be corrected by using the CALPUFF model to predict hourly ambient sulfur dioxide concentrations (1) at PSD baseline due to a baseline inventory of emitted sulfur dioxide and (2) preceding the date of concern due to a current-period inventory of emitted sulfur dioxide. This procedure also:

a. recognizes that the model's plume depletion chemistry is not linear,
b. provides total concentrations due to all emitted sulfur dioxide within the modeling domain that can be used by FLMs to assess exposures to sulfur dioxide by AQRVs and, thus, impacts on AQRVs, and
c. allows accuracy testing between the model's predicted concentrations and ambient monitoring data.

EPA's current method for gauging sulfur dioxide deterioration at a receptor will be emulated with output from the modeling of each of the two sulfur dioxide emissions inventories. The procedure that follows improves on the EPA's current method, but it still assumes that the model has skill in predicting concentrations paired in time with monitored concentrations. It begins by using the same meteorological year(s) when modeling each inventory.

Step 1. The model-predicted hourly concentrations due to each emissions inventory are averaged for each sequential 24-hour time block (day) throughout the year. The 24-hour time block correspond to the PSD 24-hour increment averaging period.
Step 2. For each receptor, the block 1 (i.e., first day of year) concentration due to baseline emissions is subtracted from the block 1 concentration due to current-period emissions. This is the paired in space and time (S & T) approach. If the difference (ΔX) is larger than the applicable PSD increment, an increment exceedance occurs. The subtraction is repeated for the remaining 364 24-hour time blocks. Conceptually, multiple exceedances are possible at the receptor.
Step 3. The highest second highest difference (HSHΔX) throughout the year among all receptors is extracted from the ΔX data pool created with Step 2.
Step 4. Results of Steps 1 through 3 will be tabulated and labeled as shown in the table below.
Step 5. Steps 1 through 4 are repeated for each modeled meteorological year.

Monitoring data cannot be used to replicate EPA's current method of gauging deterioration with the output of modeling. (See Appendix H.) Alternate procedures for gauging sulfur dioxide deterioration establish a baseline concentration due to baseline emissions of sulfur dioxide as a single value throughout the year (1) for each receptor or (2) for the Class I area. These procedures are consistent with the CAA, PSD rules, EPA regulations and model accuracy.

The first alternate procedure for gauging deterioration will be implemented by replacing Step 2 above as follows. This procedure does not assume that the model has skill in predicting concentrations paired in time with monitored concentrations.

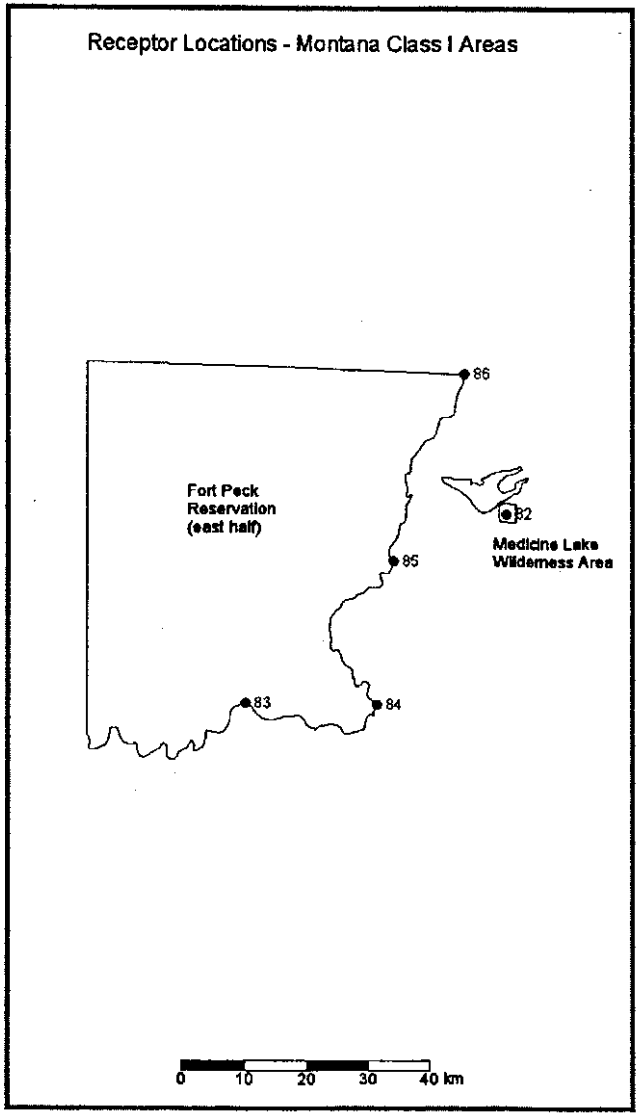
Step 2a. For each receptor, determine the model-predicted baseline concentration as the second-highest of the 365 24-hour block-averaged sulfur dioxide concentrations throughout the year due to baseline emissions of sulfur dioxide.

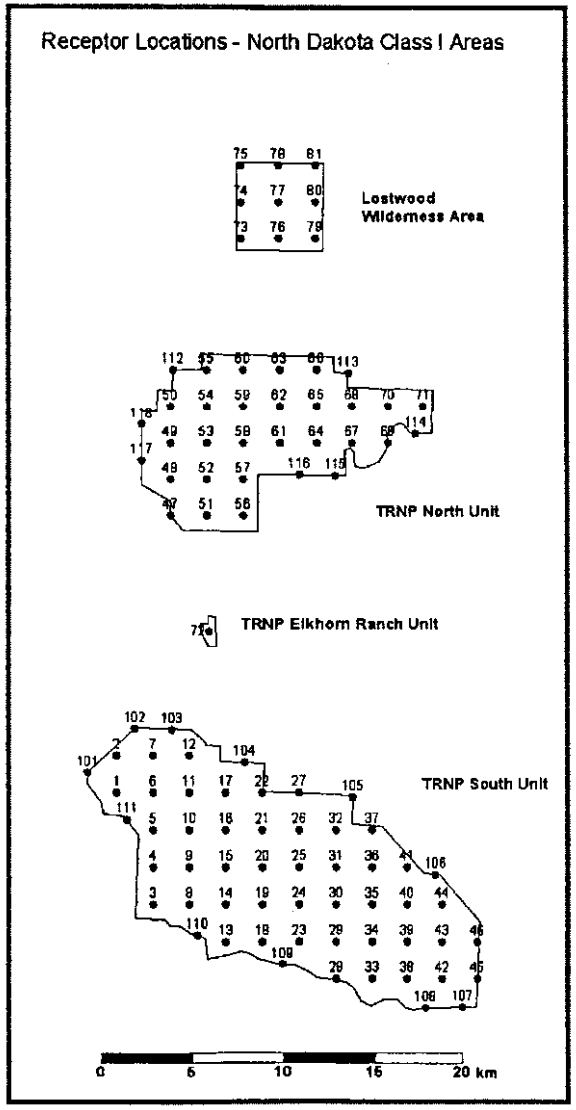
Step 2b. For each receptor, compute deterioration by subtracting its baseline concentration (a single value from Step 1) from each of the 365 model-predicted block-averaged sulfur dioxide concentrations throughout the year due to current period emissions of sulfur dioxide. This is the paired in space (S) only approach. Differences (ΔX) larger than the applicable PSD increment are exceedances; conceptually, multiple exceedances are possible at the receptor.

CALMET-CALPUFF predicted 24-hour sulfur dioxide deterioration for _____, a PSD Class I area. Source scenario: with ____ or without ____ sources granted certifications of no adverse impact by a FLM.					
Deterioration gaging method: paired in S&T ____ or paired in S only ____. When deterioration (ΔX) is 5.0 ug/m3 or larger, an increment exceedance occurs.	Meteorological Data _____				
	Year 1	Year 2	Year 3	Year 4	Year 5
Total receptors in Class I area.					
Number of receptors with at least one exceedance.					
Number of receptors with two or more exceedances, because one is allowed at each receptor.					
Highest second-highest ΔX among all receptors. (When no receptor has two or more exceedances, this number is less than 5.0 ug/m3.)					
Corresponding current concentration (ug/m3).					
Corresponding baseline concentration (ug/m3).					

When the highest of the modeled predicted HSHΔX concentrations among the modeled meteorological years is less than the increment, no second exceedance of that increment for that Class I area occurred. All procedural steps will be repeated for each PSD Class I area.

Finally, deterioration during the 2,920 consecutive 3-hour averaging periods throughout the year and exceedances of the PSD 3-hour sulfur dioxide increment of 25 ug/m3 will be tabulated for each meteorological year and PSD Class I area in the same manner.


Receptor Locations - Montana Class I Areas
86
Fort Peck
Reservation
(east half)
82
Medicine Lake
Wilderness Area
85
83
84
0
10
20
30
40 km


Receptor Locations - North Dakota Class I Areas
75 76 81
74 77 80
73 76 79
Lostwood
Wilderness Area
112 115 60 63 66 113
50 54 59 62 65 68 70 71
118
49 53 58 61 64 67 69 114
117
48 52 57 116 115
47 51 56
TRNP North Unit
TRNP Elkhorn Ranch Unit
102 103
2 7 12 104
101
1 6 11 17 22 27 105
TRNP South Unit
111
5 10 16 21 26 32 37
4 9 15 20 25 31 36 41 106
3 8 14 19 24 30 35 40 44
110 13 18 23 29 34 39 43 46
109
28 33 38 42 45
106 107
0
5
10
15
20 km

Summary.

The proposed alternate modeling protocol provides tabulated results of predicted deterioration of short-term sulfur dioxide concentrations under:

1) one meteorological input scenario – RUC2^{d} data with three years (2000, 2001 and 2002) of assimilated NWS twice-daily upper air and hourly surface meteorological data,

2) two current-period emissions input scenarios – one scenario with and the other without the two sources granted FLM certifications of no adverse impact, and

3) two scenarios of tabulation of predicted concentrations due to baseline emissions and due to current emissions – one with concentrations paired in time throughout the year at each receptor and the other with concentrations unpaired in time at each receptor.

The ARPS Data Assimilation System (ADAS) was used to 1) assimilate hourly surface weather data and terrain data with NOAA's Rapid Update Cycle version 2 (RUC-2) short-term forecast model data and 2) extrapolate these data to a 10 kilometer horizontal resolution. The assimilated and extrapolated data were compiled in a format compatible with the MM5 data ingest capability of CALMET. For this protocol, the resulting data are labeled RUC2^{d}. Tests of the correspondence between RUC2^{d} data and NWS data at low elevations (e.g., between 10 meters and 100 meters above ground) and at low wind speeds (e.g., less than 5 meters per second) may be completed, although the results of some tests are available.

Neither prior modeling protocols nor the proposed alternate protocol provide absolute results, because the science of the models and many data inputs for models are applications of known, but less than perfect, information. The data results of modeling air quality typically have been presented as numbers without uncertainty qualifiers. Accuracy testing captures the combined uncertainties of the science in the model and the inputs to the model.

The proposed alternate modeling protocol contains a provision for testing the accuracy of model predicted concentrations; such testing entails quantifying correspondence between model predicted concentrations and monitoring data. Model predicted concentrations resulting from modeling current-period (years 2000 and 2001) sulfur dioxide emissions and meteorological inputs will be used, and actual sulfur dioxide observations obtained during the same time lines will be used.

Monitoring of ambient concentrations is a measured consequence of all emitted sulfur dioxide in and surrounding the modeling domain at monitor locations, including any deterioration since PSD baseline more than 23 years earlier. The Department of Health has monitors in the North and South Units of the TRNP. For example, the second highest 24-hour monitored concentrations in the South Unit of TRNP were: for year 2000, 9.39 ug/m3; 2001, 8.81 ug/m3; and 2002, 8.30 ug/m3.

Inventories of emitted sulfur dioxide were assembled for PSD baseline and for a current period. The sum of rates of emitted sulfur dioxide for sources at PSD baseline is estimated as 29,632.7 pounds per hour (reflecting 24/7 application by the model), and the sum for sources at current period is 43,658.2 pounds per hour. The sum of rates during PSD baseline is 0.678 (67.8 percent) of the sum of current rates. These sums do not include the numerous oil and gas production sources; there were about 300 fewer of these sources during year 2000 compared to 1977-78. A crude estimate of the baseline concentration at the location of the monitor in the South Unit of TRNP is the multiplication product of the emissions ratio of 0.678 and the second highest monitored concentration for each year of monitoring data. Thus, the crude estimates of baseline concentrations are: from data for year 2000, 6.37 ug/m3; 2001, 5.97 ug/m3; and 2002, 5.63 ug/m3.

The challenge is to achieve a modeling protocol that applies the models, science and engineering judgement so as to meaningfully predict current and PSD baseline actual ambient concentrations.

Appendix A – CALMET code revision

Subroutine DIAGNO in CALMET was changed [6]

from:

```
52 IF(ICALC.LT.0) GO TO 850
C
C EXTRAPOLATE SURFACE WINDS
C EXTRAPOLATION OPTIONS:
C 1) IF IABS(IEXTRP)=1, THEN DO NOT EXTRAPOLATE FROM SURFACE DATA
C 2) IF IABS(IEXTRP)=2, THEN USE POWER LAW
C 3) IF IABS(IEXTRP)=3, THEN USE FEXTRP MULTIPLIER
C 4) IF IEXTRP=4, THEN USE SIMILARITY THEORY
C 5) IF IEXTRP<=0, THEN DO NOT USE LEVEL 1 DATA FROM UA WINDS
C
IF(IABS(IEXTRP).EQ.1) GO TO 91
```

to:

```
52 IF(ICALC.LT.0) GO TO 850
C
C EXTRAPOLATE SURFACE WINDS
C EXTRAPOLATION OPTIONS:
C 1) IF IABS(IEXTRP)=1, THEN DO NOT EXTRAPOLATE FROM SURFACE DATA
C 2) IF IABS(IEXTRP)=2, THEN USE POWER LAW
C 3) IF IABS(IEXTRP)=3, THEN USE FEXTRP MULTIPLIER
C 4) IF IEXTRP=4, THEN USE SIMILARITY THEORY
C 5) IF IEXTRP<=0, THEN DO NOT USE LEVEL 1 DATA FROM UA WINDS
C
GO TO 91
```

---

[6] The software change applies only to application of CALMET on State modeling problems and only when using NWS hourly surface and twice-daily upper air data without prognostic meteorological model data, and it may not be universally applicable in other circumstances.

Appendix B – Model accuracy conundrum

The numeric magnitude(s) of the background concentration(s) of sulfur dioxide can impact results of model accuracy tests. More specifically, the amount of over or under prediction bias in model predicted concentrations depends on the value(s) of the background concentration(s). (See section 10.1.3 of 40 CRF Part 51, Appendix W). Over or under prediction bias does not drop out in calculation of air quality deterioration or improvement as demonstrated below.

change (Δ) in actual air quality (AAQ) from baseline (b) to current period (cp)

$$\Delta AAQ = AAQ_{cp} - AAQ_b$$

modeling bias (β) with units of percent is [R – 1.0] * 100.

$$R = (MAQ + BC) / AAQ$$

$$AAQ = (MAQ + BC) / R$$

where:

MAQ = modeled air quality

BC = background concentration

with substitution, the change is air quality becomes

$$\Delta AAQ = [\ (MAQ + BC) / R\ ]_{cp} - [\ (MAQ + BC) / R\ ]_b$$

when the ratio R is the same for a wide range of concentrations, the change in air quality becomes

$$\Delta AAQ = [\ (MAQ + BC)_{cp} - (MAQ + BC)_b\ ] / R$$

when the background concentrations at cp and b are the same, the change in air quality becomes

$$\Delta AAQ = [\ MAQ_{cp} - MAQ_b\ ] / R$$

In summary, the accuracy of model predicted concentrations is dependant upon the background concentration, and changes in concentrations are dependent on model accuracy.

If a model is used to assess attainment of a PSD increment, it follows that the model can also be used to test strategies for emission reductions when attainment is not demonstrated. While modest over prediction is desirable so as to protect the PSD increment, significant over prediction can have significant implications for such strategies.

Appendix C – Dates of source permits, startup and shutdown.

Plant	Owner or Operator	Date Permit Ap Rec'd	Date Ap Complete	PTC or PTO Date	Date of Startup	Operating
Sources constructed after the PSD minor source baseline date and operating during current period						
Northern Gas	Northern Gas Products	Sep-83	Feb-84	Feb-85	never built	no
Nokota Methanol	Nokota Company	Feb-80	Jun-81	Jan-83 *	never built	no
Whitetail Gas	Amoco	Jul-80	Sep-80	Jan-83 *	never built	no
AVS U-3	Basin Electric Coop.	Jan-78	May-80	Jan-83 *	never built	no
Grasslands Gas	Bear Paw	Oct-79	unknown	Oct-80	Apr-80	yes
Stanton U-10 **	Great River Energy	Dec-77	unknown	May-79	Jul-82	yes
AVS U-1	Basin Electric Coop.	Mar-77	Jan-78 #	Feb-78	May-83	yes
AVS U-2	Basin Electric Coop.	Mar-77	Jan-78 #	Feb-78	Oct-85	yes
Coyote	Ottertail Power	Oct-76	unknown	Aug-77	Mar-81	yes
Great Plains Synfuels	Great Plain Gasification Co.	Sep-75	unknown	Jan-78 *	Mar-84	yes
Little Knife Gas	Petro Hunt	Oct-77	19-Dec-77 #	Feb-78 *	Jul-78	yes
Coal Creek U-2	Great River Energy	Sep-74	Nov-74 #	Apr-75	Jul-80	yes
Coal Creek U-1	Great River Energy	Sep-74	Nov-74 #	Apr-75	May-79	yes

date last information received from permit applicant * certifications of no adverse impact granted by a FLM
** U-1 and U-2 emissions netting based upon historical U-1 emissions to avoid PSD 24-hour increment impact for sulfur dioxide

Sources constructed after PSD baseline and retired before current period						
Temple Gas	Amerada Hess	Feb-84	na	Oct-84	unk-85	shutdown, Aug-96
Teddy Roosevelt	Western Gas Processors	Mar-79	na	Jul-79	Nov-80	shutdown, Jul-93
Perry Petrolane	Perry Processing Co.	unknown	na	Dec-77	unknown	shutdown, abt-92
Shell-Oil Gas	Shell Oil	Jun-79	na	Nov-77	Jul-79	shutdown, abt-92
Boxcar Butte	Kerr McGee	Sep-75	na	Nov-75 *	unk-76 *	shutdown, unk-87
Trenton Gas	Phillips Petroleum	Sep-80	na	Oct-82	unk-81	shutdown, unk-87

Plant	Owner or Operator	Date Permit Ap Rec'd	Date Ap Complete	PTC or PTO Date	Date of Startup	Operating
Killdeer Gas	Koch Hydrocarbon	_____	na	_____	unk-80	shutdown, unk-85

* A PTC for an expansion making the plant a major source was issued May 1976. Startup of the expansion began March 1977.

Sources operating at PSD baseline and continuing to operate during current period

Lignite Gas	Oxy NGL, Inc.	_____	na	_____	unk-61	yes
BP Amoco Oil Refinery	BP Amoco Oil	_____	na	_____	unk-54	yes
Tioga Gas	Amerada Hess	_____	na	_____	unk-54	yes
M.R. Young U-2	Minnkota Power Coop.	Sep-73	na	Jun-74	Mar-77	yes
M.R. Young U-1	Minnkota Power Coop.	Apr-73	na	Jun-73	Oct-70	yes
Stanton U-1	Great River Energy	Mar-73	na	Jun-73	unk-67	yes
Leland Olds U-2	Basin Electric Coop.	Mar-73	na	Jun-73	Nov-75	yes
Leland Olds U-1	Basin Electric Coop.	Mar-73	na	Jun-73	unk-66	yes
Heskett U-2	Montana Dakota Utilities	Apr-73	na	Jun-73	unk-63	yes
Heskett U-1	Montana Dakota Utilities	Apr-73	na	Jun-73	unk-54	yes

Sources operating at PSD baseline and subsequently retired

Royal Oak	Royal Oak, Inc.	_____	na	_____	bfr 1959	shutdown, unk-90
Neal Station	Basin Electric Coop.	Apr-73	na	_____	unk-52	shutdown, unk-85
Flying J Refinery	Flying J, Inc.	_____	na	_____	abt 1954	shutdown, unk-83
Beulah Station	Montana Dakota Utilities	_____	na	_____	1927	shutdown, unk-86

na = not applicable bfr = before unk = unknown abt = about

Appendix D – Baseline source normal operations and related source operating data.

Generally, normal source operation, a term within the rule definition for actual emissions, is the two-year period preceding and ending with the PSD minor source baseline date. An EPA interpretive regulation, i.e., the preamble to the 1980 update of PSD rules, indicates that a reviewing authority has discretion to use another two-year period when that period is more typical of a source's normal operation.

Power plants

An indicator of annual power plant operating activity is the amount of net power generation, as kilowatt hours, by the power plants. These data are available for units of power plants from the State's Tax Department for years 1990 and later; the data can be reduced to net generation per operating hour. An alternate indicator of activity is the annual utilization of a combustion system of power plants. Annual utilization is a ratio computed as the annual average hourly heat input divided by the boiler's rated heat-input capacity. The annual average hourly heat input during system operation is the annual total heat content of coal burned during operation divided by the annual total hours of operation. The rates of net generation per operating hour and annual utilization of boiler heat-input capacity correlate, indicating that utilization of boiler heat-input capacity is a viable indicator of normal source operation.

Data for computation of the utilization of the rated heat-input capacity of each coal-fired combustion system of power plants for each year from 1975 through 1982 are provided in the attached tables. The data are provided for power production sources that operated during both baseline and current periods. In addition, the average utilization of operating systems (units) within respective power plants, except GRE Stanton, also is provided for these years. Finally, the two consecutive years during which the greatest use of heat-input capacity of the plant's systems are delineated in the attached tables. The data revealed that combustion system operations following the PSD baseline date were more representative of normal source operations for some power production sources.

More representative normal operations for individual units of power plants were not considered. In addition, start-up operating problems were not considered. For example, Unit 2 of the Leland Olds plant had start-up problems that extended into year 1976, and Unit 2 of the M.R. Young plant had start-up problems during year 1978.

The annual average coal sulfur content for each year from 1975 through 1982 is also provided in attached tables. The data illustrate significant year to year variation in annual average sulfur content of the lignite coal. The coal sulfur content data were not used or considered in selecting the two consecutive years of normal source operations. The coal sulfur content for the two years of normal source operation were used in computing baseline sulfur dioxide emission rates.

Royal Oak plant

The Royal Oak plant was a charcoal briquette production plant; the plant ceased briquette production and shut down during 1990. Three spreader stoker boilers converted local lignite coal to process steam and heat for plant operations during colder season; fewer boilers were operated during warmer seasons. Two Lurgi carbonizer units provided char for briquettes.

During 1975 and 1976, the plant anticipated briquette production increases and began expansion of char production by adding two Herreschoff carbonizer furnaces. These furnaces began operation during 1976 and 1978; addition of these furnaces was a major modification to the plant. The Herreschoff furnaces operated until the plant was shut down. The sulfur dioxide emitted by these furnaces was not included in PSD baseline sulfur dioxide emissions for the Royal Oak plant.

Annual emission inventory reports from 1974 provide data on coal usage, the annual average sulfur content of that coal and the annual hours of operation of the boilers and carbonizers. These data indicated that coal usage increase dramatically during years 1978 and 1979. Because coal usage is an indicator of utilization of plant production capacity, years 1978 and 1979 are more representative of normal operations anticipated by the plant at that time.

The PSD baseline sulfur dioxide emission rate for the three boilers for 1978 and 1979 is based upon annual coal usage, the annual hours of operation of these boilers, the annual average sulfur content of that coal and a sulfur dioxide emission factor of 30S.

The baseline sulfur dioxide emission rate for the two Lurgi carbonizing furnaces is based upon coal usage of 480 tons per day (maximum operating capacity) and 10 percent down time, as no reliability (availability) data are available. Sulfur dioxide emission data from stack testing in late 1984 were used to establish an emission factor of 29.6S, because no other valid performance data were available. The annual average sulfur content of coal used during years 1978 and 1979 were used to complete the emission rate calculations.

Source locations and stack operating data

Source locations and stack operating data for all sources, except oil and gas production sources, in operation at PSD baseline and during the current period are provided in two attached tables. The longitude and latitude coordinates of several sources have been verified and updated. The coordinates are accurate to about 15 meters or less where emission point sources had been surveyed.

Operating Data for Select Units of Baseline Power Plants *

Heskett

Year	Unit 1 Hours of Operation	Unit 1 Coal Fired (tons)	Unit 1 Total Heat (Btu)	Unit 1 Boiler [1] Utilization	Unit 1 Ave. S (% by wt)	Unit 2 Hours of Operation	Unit 2 Coal Fired (tons)	Unit 2 Total Heat (Btu)	Unit 2 Boiler [2] Utilization	Unit 2 Ave. S (% by wt)	Units 1 & 2 Ave. Boiler Utilization
1975	7,562	146,608	2.06E+12	0.703	0.66	5,690	281,196	3.95E+12	0.757	0.66	0.730
1976	7,433	159,196	2.23E+12	0.774	0.75	7,668	376,017	5.60E+12	0.797	0.75	0.786
1977	7,879	171,162	2.38E+12	0.781	0.68	7,871	406,145	5.65E+12	0.784	0.68	0.783
1978	7,920	161,755	2.25E+12	0.734	0.71	7,388	342,560	4.77E+12	0.704	0.71	0.719
1979	7,940	150,922	2.11E+12	0.685	0.67	7,402	330,743	4.62E+12	0.681	0.67	0.683
1980	7,776	160,912	2.28E+12	0.758	0.75	7,739	361,847	5.13E+12	0.723	0.75	0.741
1981	7,598	153,335	2.16E+12	0.733	0.80	7,765	358,830	5.04E+12	0.709	0.80	0.721
1982	8,004	142,409	1.97E+12	0.637	0.78	7,862	335,436	4.65E+12	0.645	0.78	0.641

Footnote 1 -- rated boiler capacity for Unit 1 is 387 mBtu per hour

Footnote 2 -- rated boiler capacity for Unit 2 is 916 mBtu per hour

Leland Olds

Year	Unit 1 Hours of Operation	Unit 1 Coal Fired (tons)	Unit 1 Total Heat (Btu)	Unit 1 Boiler [3] Utilization	Unit 1 Ave. S (% by wt)	Unit 2 Hours of Operation	Unit 2 Coal Fired (tons)	Unit 2 Total Heat (Btu)	Unit 2 Boiler [4] Utilization	Unit 2 Ave. S (% by wt)	Units 1 & 2 Ave. Boiler Utilization
1975	8,254	1,335,704	1.72E+13	0.793	0.50	1,173	238,726	3.07E+12	0.510	0.53	0.652
1976	7,553	1,255,995	1.65E+13	0.833	0.45	6,776	1,958,680	2.57E+13	0.740	0.45	0.787
1977	7,894	1,306,785	1.73E+13	0.835	0.44	6,667	1,964,660	2.60E+13	0.760	0.44	0.798
1978	8,502	1,361,539	1.83E+13	0.819	0.74	7,445	2,435,160	3.26E+13	0.855	0.74	0.837
1979	8,232	1,127,701	1.50E+13	0.695	0.65	8,064	2,301,417	3.60E+13	0.870	0.65	0.783
1980	8,232	1,165,082	1.56E+13	0.721	0.85	8,064	2,098,218	2.80E+13	0.677	0.85	0.699
1981	8,102	1,104,774	1.48E+13	0.696	0.50	7,028	2,088,491	2.79E+13	0.775	0.50	0.736
1982	6,718	866,848	1.16E+13	0.659	0.54	7,269	2,099,524	2.81E+13	0.753	0.54	0.706

Footnote 3 -- rated boiler capacity for Unit 1 is 2,622 mBtu per hour

Footnote 4 -- rated boiler capacity for Unit 1 is 5,130 mBtu per hour

Ave. S = annual average coal sulfur content in units of percent by weight.

* Data sources are annual emissions inventory reports.

Operating Data for Select Units of Baseline Power Plants *

M.R. Young

Unit 1

Year	Hours of Operation	Coal Fired (tons)	Total Heat (Btu)	Boiler [1] Utilization	Ave. S (% by wt)
1975	7,773	1,470,000	1.93E+13	0.776	0.64
1976	8,188	1,581,000	2.01E+13	0.768	0.52
1977	8,003	1,527,511	1.98E+13	0.773	0.63
1978	6,714	1,427,485	1.84E+13	0.854	0.65
1979	7,870	1,508,182	2.03E+13	0.807	0.65
1980	7,858	1,454,708	1.92E+13	0.762	0.71
1981	7,456	1,363,573	1.78E+13	0.747	0.54
1982	6,538	1,146,705	1.50E+13	0.716	0.63

Footnote 1 -- rated boiler capacity for Unit 1 is 3,200 mBtu per hour

Unit 2

Hours of Operation	Coal Fired (tons)	Total Heat (Btu)	Boiler [2] Utilization	Ave. S (% by wt)
6,890	1,956,191	2.51E+13	0.579	0.65
8,064	2,508,465	3.38E+13	0.665	0.65
7,571	2,410,163	3.01E+13	0.631	0.71
7,346	2,067,550	2.70E+13	0.584	0.54
7,106	1,808,847	2.39E+13	0.340	0.63

Footnote 2 -- rated boiler capacity for Unit 1 is 6,300 mBtu per hour

Units 1 & 2

Ave. Boiler Utilization
0.717
0.736
0.697
0.666
0.528

GRE Stanton

Unit 1

Year	Hours of Operation	Coal Fired (tons)	Total Heat (Btu)	Boiler [3] Utilization	Ave. S (% by wt)
1975	7,896	683,609	9.47E+12	0.666	0.74
1976	7,272	746,205	1.04E+13	0.794	0.65
1977	7,700	737,106	1.01E+13	0.725	0.64
1978	5,466	577,004	8.05E+12	0.818	0.61
1979	7,205	728,136	1.01E+13	0.781	0.63
1980	8,250	845,822	1.19E+13	0.799	0.64
1981	8,150	816,624	1.12E+13	0.766	0.59
1982	7,211	739,001	1.02E+13	0.782	0.65

Footnote 3 -- rated boiler capacity for Unit 1 is 1,800 mBtu per hour

Unit 2 is not a PSD baseline source

Unit 1 only

Ave. Boiler Utilization
0.666
0.794
0.725
0.818
0.781
0.799
0.766
0.782

Ave. S = annual average coal sulfur content in units of percent by weight.

* Data sources are annual emissions inventory reports.

PSD baseline-period source locations and stack operating data.

Source	Unit	Longitude (degrees)	Latitude (degrees)	Stack height (m)	Base elevation (m)	Stack diameter (m)	Exit velocity (m/s)	Exit temp. (deg. K)
Beulah Power Plant	1 & 2	-101.77088	47.26346	23.0	567.0	1.7	7.6	477.0
	3, 4 & 5	-101.77088	47.26346	30.5	567.0	2.1	14.6	527.0
Neal Station	1 & 2	-100.88236	48.02377	42.4	488.0	1.8	25.0	470.0
Royal Oak Briquetting Plant	Boilers 1, 2 & 3	-102.70032	46.85862	19.2	751.0	1.4	9.8	520.0
	Carbonizer Furnaces	-102.69941	46.86010	26.2	751.0	3.4	9.4	1,172.0
Williston Refinery	Heaters + boiler 2	-103.58690	48.14555	17.3	575.0	0.9	3.2	700.0
	Boiler 1	-103.58690	48.14555	30.2	575.0	1.2	3.4	464.0
	Boiler 3	-103.58690	48.14555	9.1	575.0	0.8	6.3	464.0
R.M. Heskett Station	1	-100.88383	46.86719	91.4	514.8	2.2	20.7	461.7
	2	-100.88350	46.86664	91.4	514.8	3.7	17.4	419.7
Leland Olds Station	1	-101.32185	47.28140	106.7	518.3	5.3	19.7	450.0
	2	-101.31995	47.28080	152.4	518.3	6.7	25.0	448.6
M.R. Young Station	1	-101.21445	47.06700	91.4	597.4	5.8	18.5	449.1
	2	-101.21470	47.06625	167.6	597.4	7.6	19.2	361.8
Stanton Station	1	-101.33205	47.28650	77.7	518.3	4.6	19.9	411.1
Tioga Gas Plant	SRU Incinerator	-102.91625	48.39835	30.5	686.0	1.7	7.7	782.0
Lignite Gas Plant	SRU Incinerator	-102.54183	48.87317	38.1	598.0	0.4	19.9	893.0
Mandan Refinery	Boilers 1, 2 & 3	-102.91625	48.39835	31.8	518.3	1.7	12.5	424.7
	FCU + Crude Furnace	-102.54183	48.87317	60.7	518.3	3.4	9.9	547.0
	Alkylation Unit	-102.91625	48.39835	53.0	518.3	2.0	6.1	447.0
	Ultraformer Furnaces	-102.54183	48.87317	29.1	518.3	1.3	5.9	530.8

PSD current-period souce locations and stack operating data.

Source	Unit	Longitude (degrees)	Latitude (degrees)	Stack height (m)	Base elevation (m)	Stack diameter (m)	Exit velocity (m/s)	Exit temp. (deg. K)
R.M. Heskett Station	1	-100.88383	46.86719	91.4	514.8	2.2	20.7	461.7
	2	-100.88350	46.86664	91.4	514.8	3.7	17.4	419.7
Leland Olds Station	1	-101.32185	47.28140	106.7	518.3	5.3	19.7	450.0
	2	-101.31995	47.28080	152.4	518.3	6.7	25.0	448.6
M.R. Young Station	1	-101.21445	47.06700	91.4	597.4	5.8	18.5	449.1
	2	-101.21470	47.06625	167.6	597.4	7.6	19.2	361.8
Stanton Station	1 & 10	-101.33205	47.28650	77.7	518.3	4.6	19.9	411.1
Tioga Gas Plant	SRU Incinerator	-102.91625	48.39835	50.3	686.0	1.7	7.7	782.0
Mandan Refinery	Boilers 1, 2 & 3	-102.91625	48.39835	31.8	518.3	1.7	12.5	424.7
	FCCU + Crude Furnace	-102.54183	48.87317	60.7	518.3	3.4	9.9	547.0
	Alkylation Unit	-102.91625	48.39835	53.0	518.3	2.0	6.1	447.0
	Ultraformer Furnaces	-102.54183	48.87317	29.1	518.3	1.3	5.9	530.8
	SRU Incinerator	-100.87766	46.85201	60.8	518.3	0.6	5.7	589.0
Coal Creek Station	1	-101.15782	47.37854	201.0	602.0	6.7	25.9	358.5
	2	-101.15642	47.37858	201.0	602.0	6.7	24.9	354.5
Antelop Valley Station	1	-101.83534	47.37004	182.9	588.3	7.0	19.0	358.2
	2	-101.83556	47.37096	182.9	588.3	7.0	19.1	356.7
Coyote Station	1	-101.81480	47.22105	152.0	556.9	6.4	25.4	370.7
Little Knife Gas Plant	SRU Incinerator	-103.09806	47.29667	59.5	780.5	1.8	1.5	744.7
Great Plains Synfuels	Main stack	-101.84050	47.36160	119.8	588.3	7.0	12.1	357.1
	Start-up flare	-101.83886	47.36420	68.6	588.3	0.5	98.4	1,000.0
	Main flare	-101.83581	47.35576	76.2	588.3	1.0	100.5	1,000.0
	Back-up flare	-101.83900	47.36370	30.5	588.3	0.5	102.1	1,000.0
PPL Corp Colstrip	3	-106.6239	45.8842	210.9	988.7	7.3	26.9	361.3
	4	-106.6236	45.8842	210.9	988.7	7.3	27.6	362.7
CELP Colstrip		-106.6545	45.9748	61.0	945.1	2.5	22.6	433.2

Appendix E – Source specific sulfur dioxide emission factors.

The sulfur dioxide emission rate for lignite-fired boilers is a function of the amount of coal burned and the sulfur content of that coal, as well as the amount and form of natural sulfur scrubbing agents (e.g., sodium) in that coal, boiler design and boiler load. A current-time emission factor was calculated for units of power plants that do not have a sulfur dioxide emission control system. The factors are a mass-balanced calculation between annual sulfur dioxide emissions from recent continuous emissions monitoring (CEM) system data and corresponding coal consumption and coal sulfur-content data. The coal data were obtained from annual emissions inventory reports. All data are provided in an attached table.

An emission factor cannot exceed 40S, which has math units of pounds SO_2 per ton coal, due to the physical principal of conservation of mass, unless error occurred in coal or CEM data. S is the coal sulfur content in percent. [7] The calculated emission factor for Unit 2 of the Leland Olds plant is 40.7S, as shown on the attached table. The cause(s) for this factor could be error in tons of coal burned or a positive bias in CEM data and/or a negative bias in coal sulfur-content data. [8] CEM emissions data are derived from two CEM system monitoring components; sulfur dioxide concentrations in the stack air stream and the speed of that air stream.

A study of sulfur dioxide emissions was completed by sampling lignite-fired boilers; the sampling occurred during years 1970 through 1972. (See Gronhovd, G.H., et.al., May 1973. Some Studies on Stack Emissions from Lignite-Fired Power Plants. Lignite Symposium, May 9-10, 1973, Grand Forks, North Dakota.) Emission factors from sampling results (per data in table 3, Gronhovd, et.al.) for Unit 1 of the Leland Olds power plant and Unit 1 of the M.R. Young power plant also are provided in the attached table.

EPA reviewed and relied on data provided by Gronhovd, et.al., when developing a sulfur dioxide emission factor for combustion of lignite. (http://www.epa.gov/ttn/chief/ap42/ch01/bgdocs/b01s07.pdf) When sodium oxide in ash ranges between 2 and 8 percent, sulfur oxide emission factors range from 23.1S to 40.0S. The second highest was 37.4S, and the average was 32.3S. (Id., Table 4-1.)

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[7] The average amount of sulfur dioxide produced during an hour of combustion is equal to 40S times the coal consumed during the year divided by the number of operating hours during the year. When no sulfur dioxide is retained in combustion ash, all sulfur in coal exits into ambient air through the stack. Emission factors less than 40S occur when some sulfur dioxide is retained.

[8] Assuming that the quantity of coal which was fired is accurate and that quality CEM system data have a positive bias of 3 percent or less (http://www.epa.gov/ttn/chief/ap42/ch01/bgdocs/b01s07.pdf; Chapter 3 and 4), then an emission factor larger than 40S suggests that the average coal sulfur content was under reported or that the laboratory technique for extraction of sulfur from coal does not extract all sulfur.

Larger emission factors are conservative. Consider a scenario where CEM data are not available, such as years prior to 1995. Following AP-42, the source emitted sulfur dioxide is equivalent to the multiplication product of variables K, S and C, where K is a constant and ranges from 23.1 to 40.0, S is the average coal sulfur content in percent and C is the annual tons of coal fired in a combustion system. When K is the same for both current and PSD baseline periods, the difference in emitted sulfur dioxide is K times $[(SC)_{cp} - (SC)_{bp}]$ where cp represents current period and bp represents baseline period. Clearly, as K increases to 40, the difference in emitted sulfur also increases, because less sulfur dioxide is retained in ash.

One criterion in use of PSD baseline emission factors would allow variation in factors due to variation in combustion system design. (See attached table.) For example, Unit 1 of the Leland Olds power plant is a pulverized wall-fired unit, and Unit 2 is a cyclone unit.

Another criterion in deriving PSD baseline emission factors is that sulfur dioxide emission rates must have an apples-to-apples basis between current emissions and PSD baseline emissions – at minimum at each source. For example, there are no CEM sulfur dioxide emissions data for the baseline period. Do the results of the Gronhovd, et.al., study correspond to the CEM based factors? No basis exists for resolving the question. [9] Using Unit 1 of the Leland Olds plant as an example, the emission factor of 33.4S calculated from Gronhovd, et.al., data and the factor of 37.4S calculated from current CEM data are within 12 percent of one another. (See attached table.)

At PSD baseline, feed coal for both units of the Leland Olds plant was provided from the Glenharold Mine, which was closed in 1993. After that date, feed coal for both units was obtained from the Freedom Mine; however, after year 2000, feed coal for Unit 2 included other sources. "The SO_x emissions from lignite combustion depend on the sulfur content of the lignite and the lignite composition (viz., sulfur content, heating value, and alkali concentration)." (http://www.epa.gov/ttn/chief/ap42/ch01/bgdocs/b01s07.pdf , Chapter 2.) The alkali constituents are sodium, calcium and potassium in reactive form. Since potassium is generally present in lignites in very small amounts, the alkalis most responsible for sulfur dioxide retention in lignite fly ash are sodium and calcium. (See Gronhovd, et.al., page 6.) "The sodium oxide content is believed to have the greatest effect on sulfur conversion . . ." (http://www.epa.gov/ttn/chief/ap42/ch01/bgdocs/b01s07.pdf , Chapter 2.)

A second question is: Are the ash constituent concentrations consistent between coals from the Glenharold Mine and the Freedom Mine? Prediction of stack vented sulfur dioxide using ash concentrations for sodium oxide, silicon oxide, calcium oxide and

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[9] Significant advances have occurred in stack sampling methods, including quality control, since 1971. The method used by Gronhovd, et.al., at that time likely would not be used now. Required Relative Accuracy Test Audits of CEM systems are more rigorous. Thus, greater accuracy of CEM data would be expected.

aluminum oxide was illustrated in 1973. (See Gronhovd, G. H., et.al., May 1973. Technology and Use of Lignite. Information Circular 8650, Bureau of Mines, United States Department of the Interior.) Test data obtained at five power plants were used to establish the regression equation for the prediction. (Id., equation 5 on page 93 and figure 59 on page 95.) One of the five power plants was the Leland Olds power plant; only Unit 1 was operational at the time of the plant testing, because Unit 2 was constructed after 1973. Regression equations for prediction of emitted sulfur dioxide for each of the plants, including the Leland Olds plant, were not reported, which is likely due to the limited test data for each individual plant.

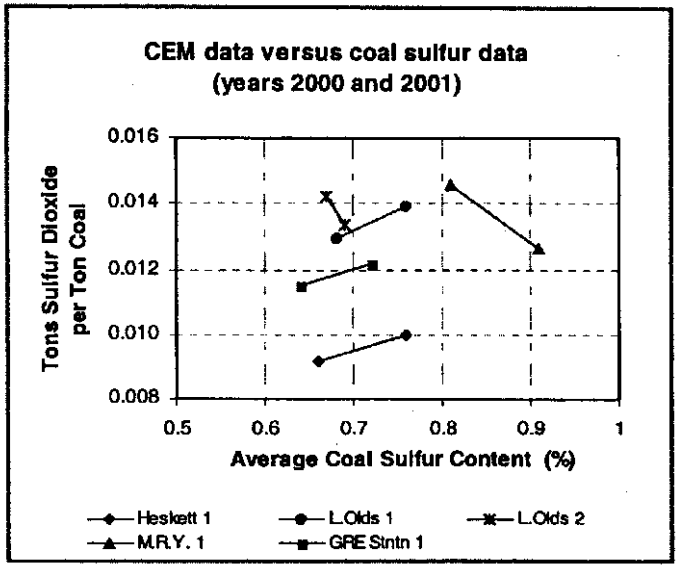
Unit 1 coal fly ash concentrations for sodium oxide, silicon oxide, calcium oxide and aluminum oxide also were reported in 1996. (See Pflughoeft-Hassett, Debra F., April 1996. Survey and Demonstration of Utilization Potential of North Dakota Lignite Ash Resources. Energy & Environmental Research Center, Grand Forks, North Dakota, page 14.) The Unit 1 ash constituent data for coal obtained from the Glenharold Mine and the Freedom Mine are provided in the table at right. The data indicate no apparent significant difference in coal ash concentrations of the four ash constituents between mines.

Ash constituent concentrations (percent by weight) for Unit 1 of the Leland Olds power plant.

Ash constituent	Glenharold Mine (range of values)	Freedom Mine
sodium oxide	5.1 – 8.8	7.55
silicon oxide	30.7 – 37.5	29.09
calcium oxide	16.2 – 20.2	21.14
aluminum oxide	11.0 – 13.8	13.06

Additional questions are: What might be the explanation for the sulfur dioxide emission factor of 40.7S for Unit 2 of the Leland Olds plant, and what might be alternatives to that factor? (See attached table.) The 40.7S factor provides a baseline emission that is identical to the results of the following calculation sequence. First – calculate an emission factor, EF, for the current time period as the ratio of total emitted sulfur dioxide emissions from CEM data and total coal fired in the combustion system, and second – calculate the multiplication product of EF, the ratio of baseline period average coal sulfur to current period average coal sulfur and total baseline coal fired.

The weighted average sodium oxide content of the lignite ashes for Unit 2 of the Leland Olds plant declined from 3.4 percent during 1977-1978 to 3.0 percent during 2000-2001, which are the baseline-period years and current-period years. The minor decline in sodium oxide suggests that the sulfur dioxide emission factor for Unit 2 during current time would be modestly larger than the factor during the baseline. [Note. A statistical test of the data, such as the Student's t-test, to determine whether differences in mean sodium oxide content of ashes for the two time periods are significantly different was not completed.]



$Y2000(S_{AVE} / (T_{SO2}/T_{COAL}) / Y2001(S_{AVE} / (T_{SO2}/T_{COAL})$	
Heskett 1	0.948
L. Olds 1	0.963
L. Olds 2	1.097
M.R.Y. 1	1.298
GRE Stntn 1	0.940

Rates of sulfur dioxide emission for the state's lignite-fired power plants, that are calculated using EPA's AP-42 method, have an accuracy uncertainty due to coal sulfur-content data and to CEM data. Data in the attached table are plotted on the chart at left. The consistency between the two years of data is shown by the double ratio in the chart at right. Four of the five double ratios at right are within 10 percent of 1.0, which indicates that, year to year, the CEM and coal sulfur data may not be reasonably consistent for Unit 1 of the M.R. Young plant.

Initially, CEM system measured stack air stream speeds were biased high. EPA corrected CEM system calibration methods in 1999, and EPA has reviewed the CEM data from state sources and found it of adequate quality. (http://www.epa.gov/ttn/chief/ap42/ch01/bgdocs/b01s07.pdf , Chapters 3 and 4.)

The sulfur in the state's lignite coal is highly variable; thus, annual averages of sulfur for years 2000 and 2001 as in emissions inventory reports for Unit 1 of the M.R. Young plant may not adequately represent the sulfur in coal fired in its combustion system. Nevertheless, the emission factor of 33.3S calculated from Gronhovd, et.al., data and the factor of 31.8S calculated from current CEM data are within 5 percent of one another. (See attached table.) Feed coal for Unit 1of the M.R. Young plant has been and is obtained from the Center Mine, which is adjacent to the plant.

The data analysis above does not explain the CEM based sulfur dioxide emission factor of 40.7S for Unit 2 of the Leland Olds plant. The emission factor relies on data provided by the operator in annual emissions inventory reports. These reports indicate only lignite was used to fuel combustion systems. However, some Wyoming sub-bituminous coal was blended with lignite for use in Unit 2 after mid-2001. The heat and sulfur contents of the sub-bituminous coal are different than local lignite; the heat content was about 8,000 Btu per pound, and the sulfur content ranged from 0.4 to 0.55 percent by weight. Because the heat content is higher and the sulfur

content lower than local lignite, coal use data were reviewed by the operator to isolate those parts of the year when lignite only was used; a CEM based sulfur dioxide emission factor was calculated accordingly, but the result remained larger than 40S.

The sulfur contained in coal emerges – after combustion – in gas vented to the atmosphere and in fly ash, bottom ash or slag. Bulk analyses of fly and bottom ashes indicate that amounts of sulfur trioxide in these ashes varies widely. Data on amounts of ash after combustion and the amounts of sulfur trioxide in the ash can be used to estimate amounts of sulfur dioxide vented to the atmosphere. An example of such data are provided in the table at right; the data on coal ash content were obtained from Leland Olds plant personnel. If the sulfur trioxide data typify ashes for both boilers at the Leland Olds plant during years 2000 and 2001, [10] about 21.2 percent of the coal sulfur content would have been retained in ash of Unit 1 and about 11.8 percent in the ash of Unit 2, which are equivalent to emission factors of 31.5S and 35.3S, respectively. Both factors are less than the CEM based factors shown in the attached table.

Sulfur contained in ash.

Bulk Analysis	Fly Ash	Bottom Ash
coal ash content (%)		
Leland Olds, Unit 1	5.6	2.4
Leland Olds, Unit 2	2.4	5.6
sulfur trioxide in ash (%)	6.0	1.0

Clearly, the CEM based emission factors of 37.4S for Unit 1 and 40.7S for Unit 2 of the Leland Olds plant are suspect, because sulfur is retained in boiler ash and slag. [11] And, there likely is a bias in Unit 2's CEM system measurements, because it is unlikely that there is a bias in the average annual coal sulfur content for Unit 2 but not for Unit 1. Consequently, any adjustment to this factor necessitates a corresponding adjustment to the current-period emission rate. Therefore, the sulfur dioxide emission factor for Unit 2 could be 38.7S as for year 2000, or 40.7S as an average for both years, or 35.3S as estimated above. As described above, larger factors are increasingly conservative.

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[10] Sulfur trioxide contents, percent by weight, in ash for Unit 1 of the Leland Olds plant were: fly ash, 6.2; bottom ash 0.9. Sulfur trioxide contents for Unit 1 of the M.R. Young plant were: fly ash, 6.7; slag 0.1. (Pflughoeft-Hassett, Debra F., April 1996. Survey and Demonstration of Utilization Potential of North Dakota Lignite Ash Resources. Energy & Environmental Research Center, Grand Forks, North Dakota.)

[11] Relative Accuracy Test Audits of the CEM system for Leland Olds Unit 2 were conducted for years 2000 and 2001. System flow measurements were biased high by an amount greater than three percent for year 2001; no bias correction to CEM data was applied by the operator. Application of a bias correction to year 2001 CEM data would reduce the CEM based emission factor of 42.5S to 39.8S.

In consideration of the information and data presented above, the alternate PSD baseline emission factors for baseline power plants are shown in the attached table. The sulfur dioxide emission factors in the attached table were used to calculate alternate baseline sulfur dioxide emission rates using baseline-period coal consumption and coal sulfur-content data. The baseline period is the two consecutive years representative of normal operations, as presented in Appendix D.

The baseline rate for Unit 2 of the Leland Olds plant has been adjusted from 7,690.3 lb/op-hr based on the factor's multiplier of 40.7 to 7,312.4 lb/op-hr based upon the factor's multiplier of 38.7. Consequently, the current period emission rate for this unit also has been adjusted from 8,566.0 lb/op-hr to 8,145.1 lb/op-hr.

At PSD baseline, Unit 2 of the Heskett plant was a pulverized lignite-fired boiler as was/is Unit 1. Thus, the PSD baseline emission factor for Heskett's Unit 2 is set to be the same as Unit 1. Feed coal for both units of the Heskett plant has been and is obtained from the Beulah Mine.

Data provided by Gronhovd, et.al., for Unit 1 of the M.R. Young plant as listed in the attached table, as well as other state lignite-fired units of power plants are used. [12]

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[12] The Wm.J. Neal plant also was sampled. This plant consisted of two pulverized coal-fired boilers; feed coal was obtained from the Velva Mine, which was located southwest of the plant. The sulfur dioxide emission factor was 32.9S pounds sulfur dioxide per ton coal (per data in table 3, Gronhovd, et.al.). This factor has been used to calculate the alternative baseline sulfur dioxide emission rate for the Neal plant.

The Beulah power plant was not sampled. The plant consisted of five units. Boilers 1, 2 and 3 were chain grate stokers, and boilers 4 and 5 were spreader stokers. An emission factor of 27.0S was used for boilers 4 and 5, as well as for boilers 1, 2 and 3. Boilers 4 and 5 were spreader stokers as is Unit 1 of the Heskett plant and boilers 3, 4 and 5 vented through a common stack as of the PSD minor source baseline date.

Calculated sulfur dioxide emission factors.

Company / Plant	Current Boiler Type	Parameter *	Year 2000	Year 2001	Calculated Emission Factor ** (lb / ton)	Energy Research Lab. *** (lb / ton)	Alternative Baseline Emission Factor (lb / ton)
MDU / Heskett Unit 1	spreader stoker	coal burned (tons) average sulfur content (%) sulfur dioxide emissions (tons)	111,114 0.66 1,019	102,134 0.76 1,022	27.0		27.0
MDU / Heskett Unit 2	fluidized-bed	coal burned (tons) average sulfur content (%) sulfur dioxide emissions (tons)	340,598 0.66 1,778	458,243 0.76 2,625	15.4		27.0
Basin Electric / Leland Olds Unit 1	pulverized wall-fired	coal burned (tons) average sulfur content (%) sulfur dioxide emissions (tons)	1,302,256 0.68 16,864	1,093,610 0.76 15,237	37.4 (2000 - 38.1 2001 - 36.7)	33.4	37.4
Basin Electric / Leland Olds Unit 2	cyclone	coal burned (tons) average sulfur content (%) sulfur dioxide emissions (tons)	2,140,601 0.69 28,587	2,546,797 0.67 36,219	40.7 (2000 - 38.7 2001 - 42.5)		38.7
Minnkota / M.R. Young Unit 1	cyclone	coal burned (tons) average sulfur content (%) sulfur dioxide emissions (tons)	1,434,793 0.91 18,095	1,590,495 0.81 23,179	31.8 (2000 - 27.2 2001 - 36.0)	33.3	33.3
Great River Energy / Stanton Unit 1	pulverized wall-fired	coal burned (tons) average sulfur content (%) sulfur dioxide emissions (tons)	666,577 0.64 7,660	744,341 0.72 9,046	34.7		34.7

* Amounts of coal burned and average sulfur content of that coal taken from annual emissions inventory reports. Amounts of emitted sulfur dioxide from CEM data as archived on EPA's Acid Rain Program data base.

** Calculated emission factor equals sulfur dioxide emissions (as measured by CEM) divided by the product of the average sulfur content and the amount of coal burned.

*** Gronhovd, G.H., et.al., May 1973, Some Studies on Stack Emissions from Lignite-Fired Power Plants, 1973 Lignite Symposium, May 9-10, 173, Grand Forks, North Dakota.

Appendix F – Oil and gas production source inventories.

Baseline sulfur dioxide emissions inventory

Emissions of SO_2 from oil and gas wells typically come from treaters or flares. Treaters separate the fluids in the crude oil for later transport or disposal. Flares burn the waste gas, converting the H_2S into SO_2. Since the mid-1980s, the Oil and Gas Division has been collecting well production data on the amount of wellhead gas flared monthly and the amount of wellhead gas used in firing the treater or other on-site equipment (lease use). These two monthly gas totals, the amount flared and the amount of lease use , were used by the Department of Health to calculate the SO_2 emissions from a well's flare and treater, respectively.

The Department has been requiring well operators to measure and report the H_2S content (percent) of the wellhead gas since the 1980s. The Department adds this data to a database controlled by the State's Oil and Gas Division. The H_2S data are generally not concurrent with the gas production data. In addition, H_2S data for many older wells are unreliable. No H_2S data exists for some wells; in these cases, it was necessary to substitute for the missing H_2S data from a nearby similar well.

A well's SO_2 emission rate is calculated by multiplying a monthly total of wellhead gas produced by the percent of H_2S in the gas and dividing by the number of days of production in the month (as well as some other conversion factors). Data from additional months were usually included to obtain an average emission rate over several months or a year.

The Oil and Gas Division believes the gas production data back to about 1987 are reliable. Early gas production data are considered somewhat unreliable because, until about the early to middle 1980s, the product of value from the wells was oil, and the gas was considered a waste product. Records were kept of oil production for the benefit of the owners, operators, and the State. However, the gas was a waste product disposed by flaring, etc., and data on gas production were not consistently and reliably reported or recorded until the value of the gas improved in the mid-1980s.

Some data on total wellhead gas production are available back to 1976-77, the two years before the baseline date, but the data often represent the amount of gas sold to a gas processing plant. The amount of wellhead gas used in the treaters or flared, which is necessary for emissions calculations, was not consistently reported before the mid-1980s and was available for a few wells in 1976-77. Based on the Oil and Gas Division's judgment that gas production data before 1987 were not completely reliable, the Department of Health used 1987-1988 gas production data to calculate an estimate of the baseline emission rate for wells that existed during the 1976-77 time period.

The Department previously conducted the "Williston Basin Regional Air Quality Study" (WBS, 1990). The Williston Basin Study processed oil and gas H_2S and production data for emissions data for all North Dakota wells producing during the period November 1987-March 1988. The emissions data from the 1987-88 study were applied to wells producing during 1976-77 as an estimate of baseline emissions. Well identifying information, such as the wells' names, file numbers, field names, and locations for all wells producing during 1976-77 were extracted from the Oil and Gas Division database. Only wells that actually existed and were producing during 1976-77 were included in the baseline emissions inventory. For wells that existed in both time periods, the 1987-88 emissions data were used. For wells that produced in 1977 but not in 1987, there were no emissions data directly available. The average emission rate for all wells in the same field was calculated and substituted into the baseline inventory for each well of similar type, where data were available. In cases where data were needed for a 1977 well in a field that did not produce gas during 1987-88, a field-average emission rate from a similar, nearby field was used.

Much of the gas produced during 1987-88 was sold to gas processing plants and not flared. Many of these gas plants didn't exist in 1976-77, so that all of that sold gas would have been flared. In cases where a 1977 well was not selling gas to a gas plant, all of the gas produced at that well in 1987, except for lease-use gas, would have been flared in 1977. The Williston Basin Study data were applied to these wells by adding the 1987-88 sold gas amount to the flared gas amount before calculating the flare emissions. Wells where gas was sold in both periods or where gas was not sold in both periods were assigned the Study's flare emissions.

The remaining task was to determine which wells were selling gas in 1976-77. Gas processing plants receive gas from oil and gas wells through a pipeline, or gas-gathering system, that connects the wells to the gas plant. In 1977, the Tioga Gas Plant, near Tioga, was connected to the largest gas-gathering system in the state at the time, reaching from about 20 miles north of Tioga southward to southeastern McKenzie County southeast of Watford City. The Tioga pipeline connected to at least 20 separate oil and gas fields. The Lignite Gas Plant, near Lignite, was connected to a smaller gas-gathering system serving about nine fields in Burke County. Two small gas plants, the Red Wing Creek Gas Plant and the Boxcar Butte Gas Plant in western McKenzie County, also were operating in 1977 and received gas from only two isolated fields.

All other fields in the rest of the state were not served by any gas-gathering systems in 1977 and could not have sold gas. Later development in west-central North Dakota between Williston and Belfield triggered the construction of three additional gas plants and extensive gas-gathering systems in this area by 1987. Many wells in this part of western North Dakota were selling gas by 1987 where no gas plants existed in 1977.

When applying the above procedure for flare emission rates, it was assumed that any field connected to a gas-gathering system in 1977 was selling gas in 1977. Therefore, all wells in fields connected to the Tioga and Lignite gas-gathering systems and the Red Wing

Creek and Boxcar Butte gas plants were assumed to be selling gas both in 1976-77 and 1987-88 and so were assigned flare emission rates from the Williston Basin Study inventory. However, many other wells in western North Dakota were not connected to gas-gathering systems in 1977 and, thus, given credit for higher flare emissions in 1977 because of sold gas in 1987-88. The result of this procedure was an SO_2 emissions inventory for all oil and gas wells producing in 1976-77 that reflected gas production levels back to 1987, using the earliest reliable gas production data, and appropriately accounted for gas sold to gas processing plant.

Exception to baseline data and baseline inventory

The Department located gas production data for 1976-77 for a small number of wells in three oil and gas fields that appeared reliable, internally consistent, and reasonably complete for that period. Gas production data for 1976-77 exist for 29 wells in Little Knife Field, 2 wells in Elkhorn Ranch Field and 6 wells in Mondak Field. All three fields are in western North Dakota – partially within 50 km of Theodore Roosevelt National Park (TRNP). Little Knife Field is a large field more than 25 km southeast of the TRNP North Unit and mostly in western Dunn County. Elkhorn Ranch Field is a smaller field directly east of the TRNP Elkhorn Ranch Unit in northern Billings County. Mondak Field is another large field at least 30 km west of the TRNP North Unit in western McKenzie County. There were appropriate gas production data available for all Little Knife wells producing in 1976-77, for all three Mondak wells within 50 km of Class I areas, but not for most Elkhorn Ranch wells.

These data included all of the gas production data necessary for calculating an SO_2 emission rate as described earlier in this section, including monthly lease-use gas volumes, flared gas volumes and days of production. However, updated SO_2 emission rates were not included in the inventory for all wells in Little Knife, Elkhorn Ranch and Mondak Fields. The SO_2 emission rates for the Elkhorn Ranch and Mondak wells were relatively small and, thus, were not expected to greatly impact the results. Also, the Mondak wells were fairly distant from the Class I areas, located 30-50 km west of TRNP North Unit. It was concluded that the changes in the Elkhorn Ranch and Mondak source parameters would not significantly affect results of modeling analysis.

However, the baseline emission rates that are based on the Williston Basin Study data for the 29 Little Knife wells were relatively large and had a major impact on baseline concentrations at the Class I areas. Revised emission rates based on the 1976-77 gas production data could also be quite large and impact the results of the Class I modeling analysis. Therefore, baseline emission rates using the 1976-77 gas production data were calculated for the 29 Little Knife wells. Because the revised treater emission rates were very small, especially compared to the very large flare emission rates, only the updated flare emission rates were included. Revised values for the Little Knife flares' stack parameters were also calculated.

Previously, the Department modeled oil and gas well emissions based on the five-month average over the months November through March, but averaging over other periods has been considered. On the SO_2 baseline date, December 19, 1977, the Little Knife Field was in the middle of its initial development. Thirty-four wells were producing gas by the end of 1977 and many would be added later. The oldest Little Knife well produced on 224 days over 11 months in 1977. Most Little Knife wells produced on fewer days over 3-9 months of 1977. The newest baseline Little Knife well produced on only four days in December 1977. Clearly, the number of days and months of production were variable in 1977 and it would be difficult to define a representative period of emissions for all wells. Wells that produced for only a few days in December 1977 might have very different production or emission characteristics in 1977 from wells that produced most of the year.

A solution to the problem was to add additional months of gas production data in 1978, even though it was after the baseline date. This is justifiable because adding more months of production data produces more representative emission rates over the entire field that are more reflective of normal operations. However, the large amount of gas produced in Little Knife Field warranted the construction of a gas-processing plant. In 1978, Warren Petroleum Company, a Division of Gulf Oil Corporation, constructed the Little Knife Gas Plant to process the gas. Although the plant started receiving gas in July 1978, it was not fully operational until November 1978. Prior to the gas plant becoming fully operational much of the gas produced in Little Knife Field was flared (combusted).

In the interest of conserving the natural gas, at the March 28, 1978, Industrial Commission Hearing on Little Knife Field operations, Governor Arthur Link asked Gulf Oil Corporation, the operator of Little Knife Field, to voluntarily reduce the daily rate of production per well until the Little Knife Gas Plant began operations. In a letter to Governor Link dated April 6, 1978, Gulf Oil Corp. agreed to reduce the daily production rate of all wells in Little Knife Field to an average of 100 barrels of oil per day per well except for new wells undergoing initial production tests to evaluate the wells and reservoirs. The reduction was effective April 6, 1978 and continued until gas-handling facilities were in operation.

The period of reduced production from April until about November 1978, based on the Governor's request, does not represent normal operations for Little Knife Field and should not be included in the calculation of baseline emissions. Thus, baseline emissions for Little Knife wells were calculated as an average emission from the start of well production through March 1978. The number of months of data used in the calculation are often less than the difference between the last and first months, because at least one month of data is missing for each well. The result is that the Little Knife wells' baseline emission calculation included between three months of data and ten months of data depending on the well.

Other than the different gas production data and number of months, the emission calculation was the same as used before. The result of the revised calculation of Little Knife flare emissions is that the emission rates for some wells increased and some decreased, with about equal numbers of wells increasing as decreasing. However, the total baseline emissions (flares only) for the whole field increased about 9% from 935 grams/second to 1015 grams/second (1977-78 raw production data). Much of the increase in Little Knife Field emissions is due to these wells previously modeled at average emission rates. This suggests that the Little Knife Field average emissions were higher in 1977-78 than the Williston Basin Study data indicated.

Current period sulfur dioxide emissions inventory

The current period inventory of oil and gas production sources (flares and treaters) includes year 2000 source data only because of the man power effort required. Year 2000 actual emission rates reflecting annual average operation for oil and gas production sources were derived from the State Industrial Commission's (SIC) oil and gas data base. The data base includes information on gas production (flared and lease use), the H_2S content of the gas, such that SO_2 emission rates for well-site flares and treaters can be calculated. Dynamic stack operating parameters for these sources were derived from the calculated heat of combustion using procedures described in a previous report, [13] and modified using SCREEN3 [14] adjustments for effective flare plume height and radiational heat loss. Flare and treater stack height were obtained directly from the SIC data base.

Flare and treater source inventory data

The sulfur dioxide emitted by those oil and gas production sources , flares and treaters, located within 50 kilometers of respective PSD Class I areas will be included as CALPUFF input data. Therefore, a separate modeling of each Class I area using only those sources within 50 kilometers of that area will be completed. Results at Class I area receptors from these modeling runs will be merged with results of modeling other sources using the program CALSUMOG.

A table of data for the number of flares and treaters located within 50 kilometers of each of the four PSD Class I areas in North Dakota and the total sulfur dioxide emissions of those flares and treaters follows on the next page below. Maps of the flares and treaters located within 50 kilometers of the North and South Units of TRNP are attached.

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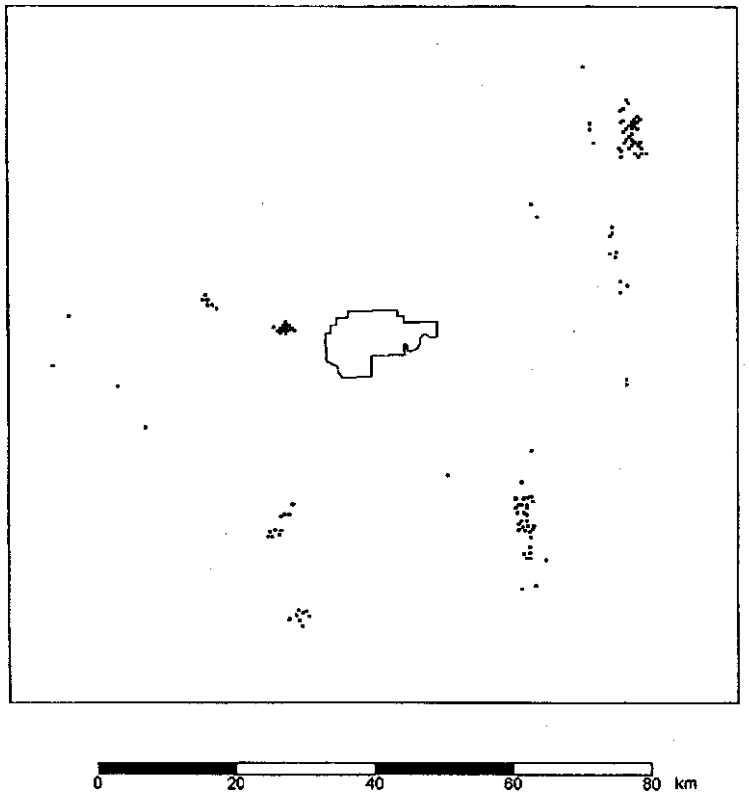
[13] NDDH, 1990. Williston Basin Regional Air Quality Study. North Dakota Department of Health, Bismarck, North Dakota, 58506.

[14] EPA, 1995. SCREEN3 Model User's Guide. Publication No. EPA-454/B-95-004, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina, 27711.

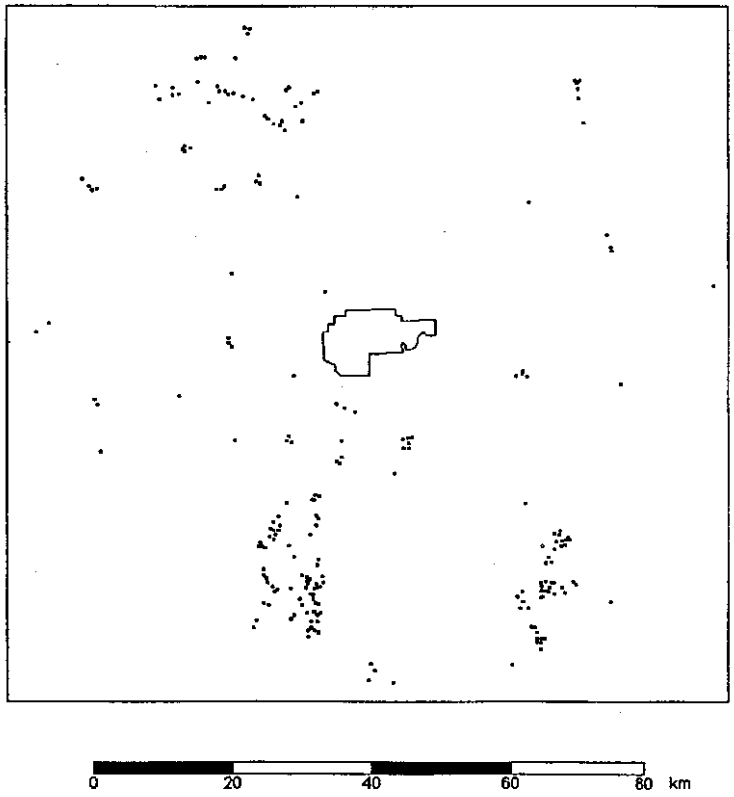
Statistical summary of oil and gas production sources located within 50 kilometers of PSD Class I areas. *				
	Baseline period		Current period	
Class I area	Number of sources	Total emission rate (pounds per hour)	Number of sources	Total emission rate (pounds per hour)
TRNP – South	196	824.6	262	318.3
TRNP – Elkhorn	248	8,030.1	310	460.6
TRNP – North	208	8,305.3	261	551.4
Lostwood WA	506	424.0	149	157.1
* Some sources are located within 50 kilometers of two or three TRNP areas and, therefore, are included in tabulated data for each area.				

Locations of flares and treaters within 50 kilometers of the North Unit of TRNP.

Baseline period

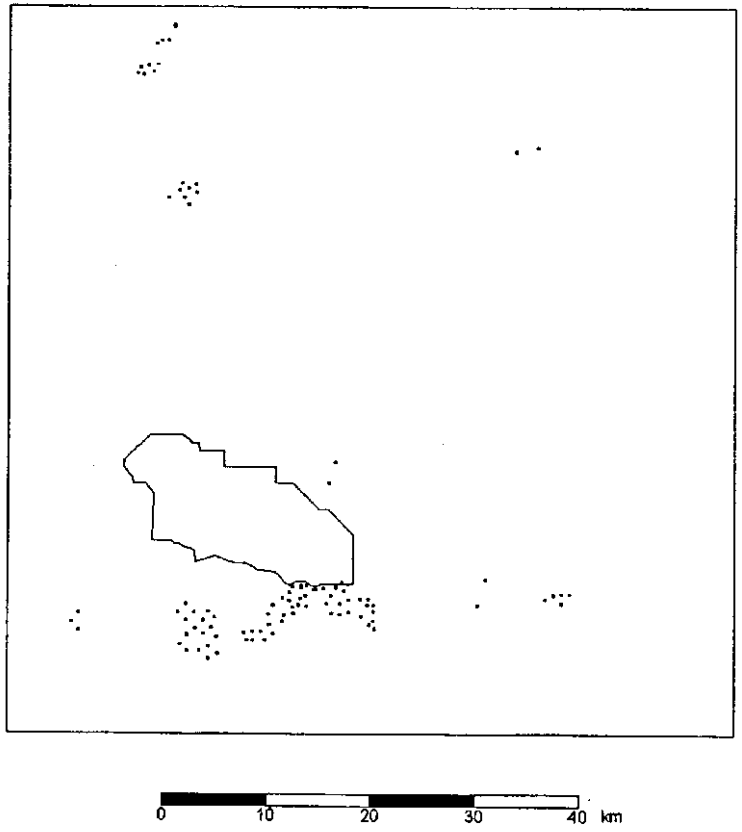


Current period

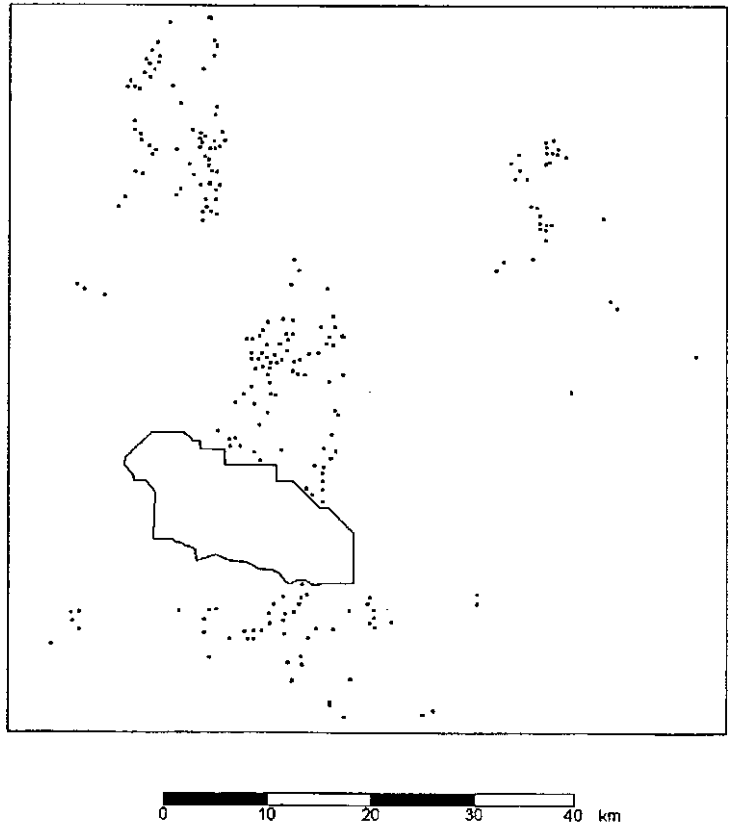


Locations of flares and treaters within 50 kilometers of the South Unit of TRNP.

Baseline period



Current period



Appendix G – Correspondence between emissions data and monitoring data.

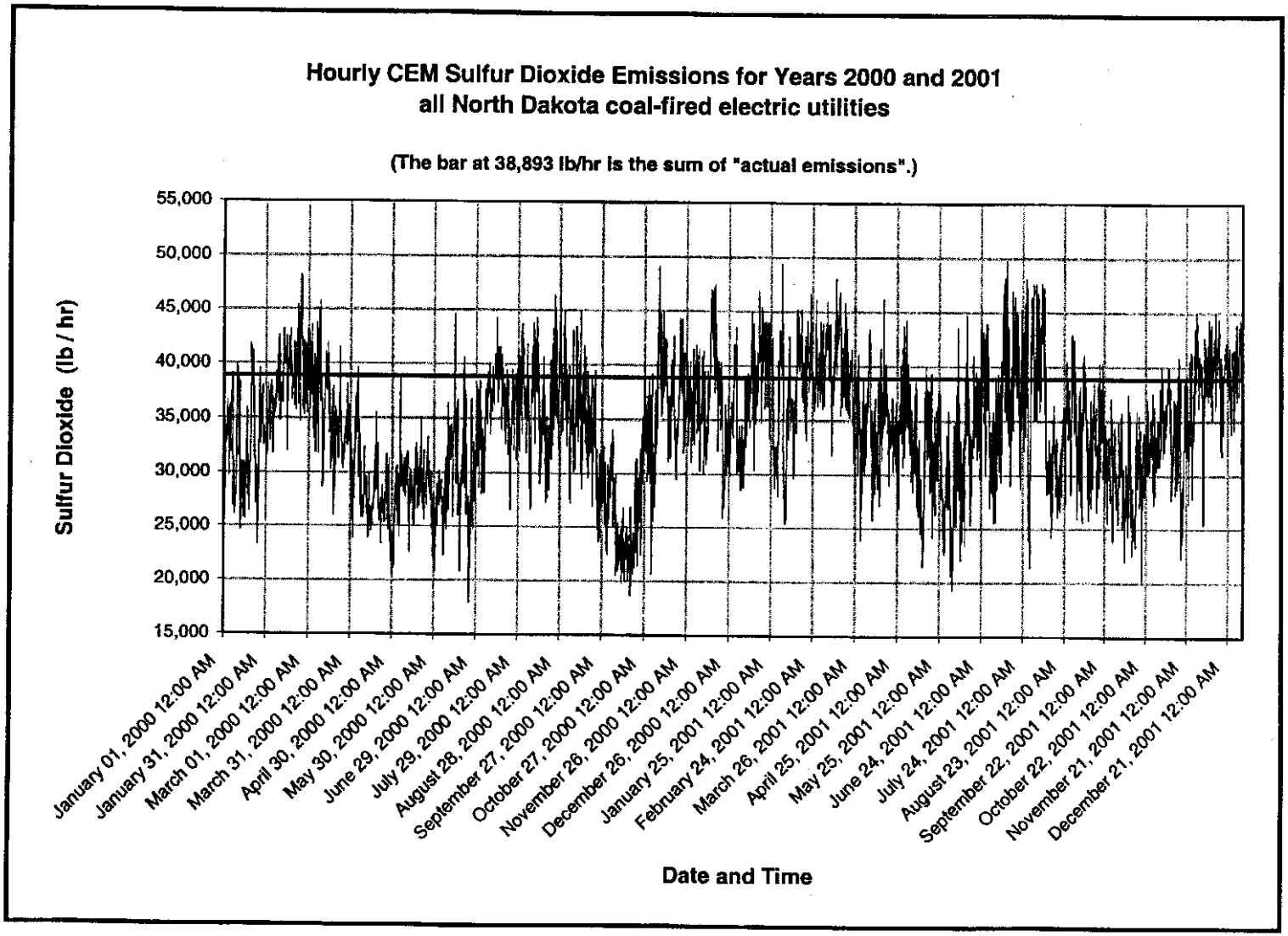
The sulfur dioxide emission rate for each source used as input for the CALPUFF model in this protocol is not time variable but rather a constant that is applied 24/7/52 by the model. The emission rate for a source is often time variable, as illustrated by an attached figure which displays the total sulfur dioxide emitted by the coal-fired electric utilities in North Dakota for all 17,544 hours throughout years 2000 and 2001. Another figure enhances time resolution by displaying the total emitted sulfur dioxide each hour during the months of November 2000 through February 2001.

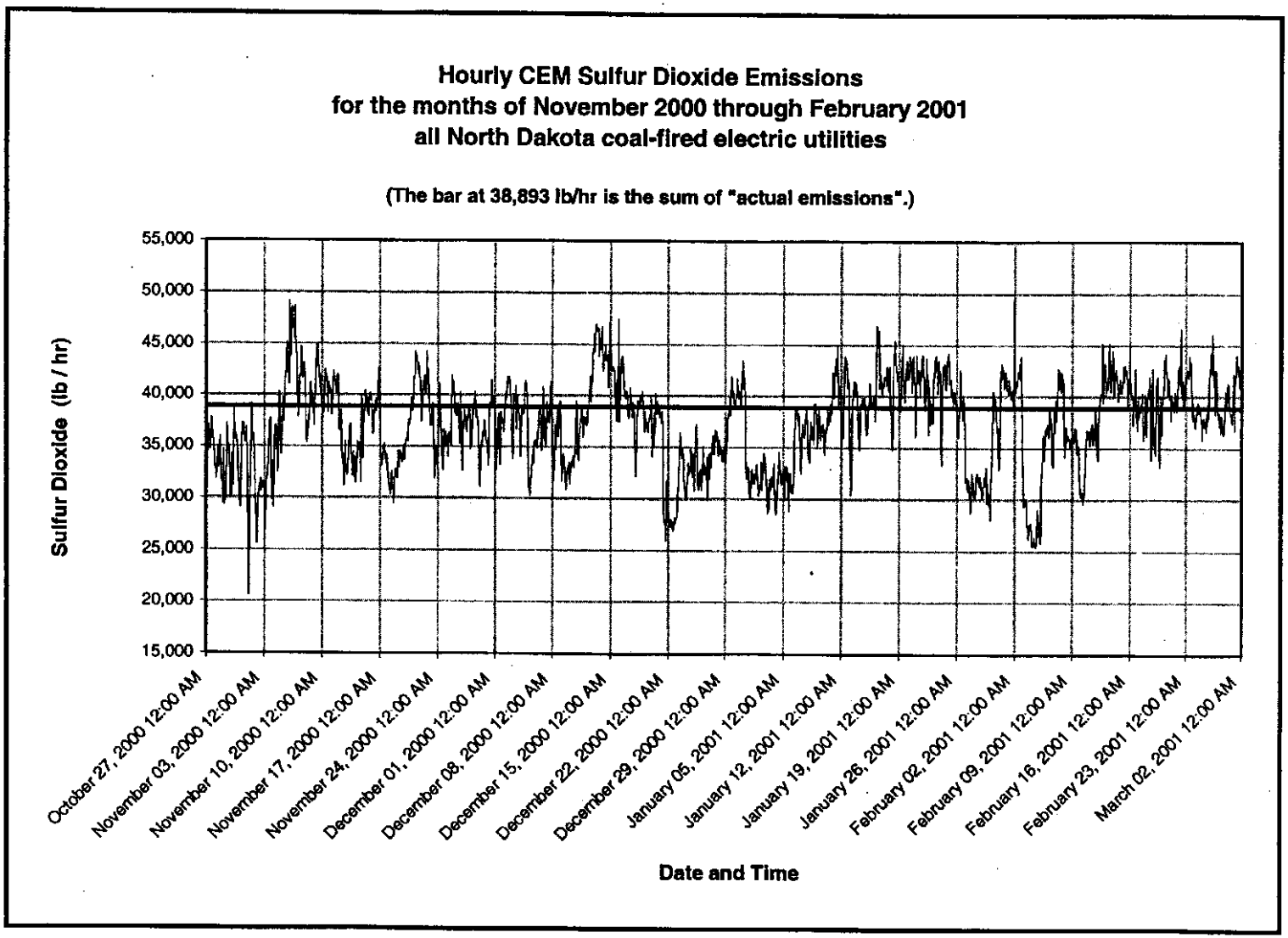
Actual emissions, which is the annual total emitted sulfur dioxide during operating hours as defined by rule, can be larger or smaller than the CEM measured rate for a specific hour. The sum of year 2000-2001 average actual emissions for the coal-fired electric utilities is also shown on the attached figure. The total hourly sulfur dioxide emitted by these sources exceeds the sum of actual emissions about 23.6 percent of the 17,544 hours during the two years.

An estimate of the risk of under predicting actual observed sulfur dioxide concentrations at monitoring sites is the multiplication product of 23.6 percent and the frequency of easterly winds that could transport emitted sulfur dioxide westward and across PSD Class I areas. Based upon 900 millibar pressure altitude wind directions from NWS rawinsondes launched at Bismarck, the frequency of wind directions from east-northeast through southeast is about 15 percent. The calculated risk is about 3.5 percent. However, when emission rate inputs are actual emissions as previously indicated in the protocol, the CALMET and CALPUFF models over predict the highest actual observed sulfur dioxide concentrations.

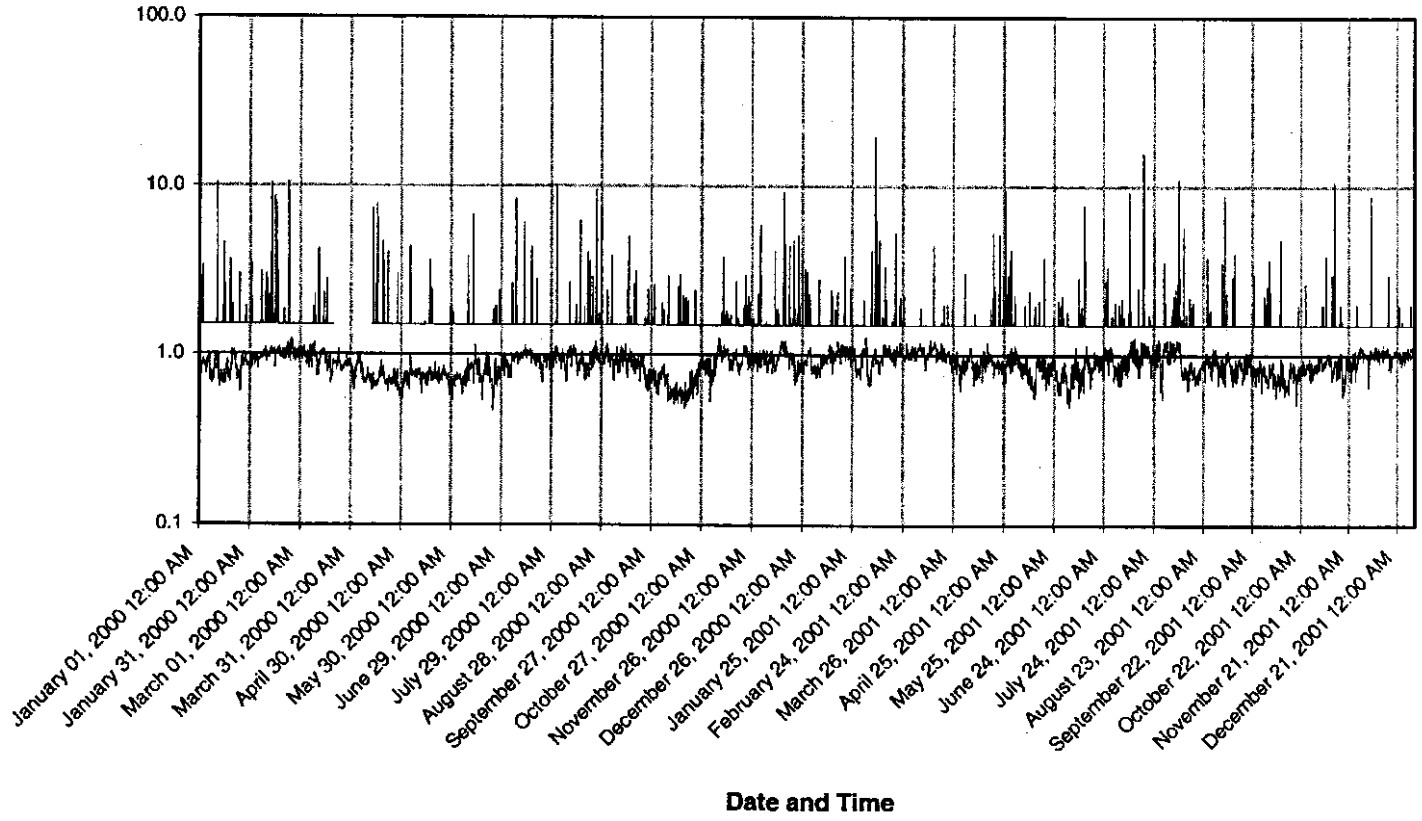
Some sources are located at greater, or shorter, distances from PSD Class I areas than are other sources. Distances between sources, other than oil and gas production sources, and Class I areas range from about 30 kilometers to 200 or more kilometers. Therefore, the time of travel of emitted sulfur dioxide to PSD Class I areas varies among sources. The time of travel also depends on the speed of the wind. Two additional attached figures display hourly emitted sulfur dioxide and hourly sulfur dioxide concentrations at the monitoring site located in the South Unit of the TRNP. Only 1,796, or 10.2 percent, of the 17,544 hours during years 2000 and 2001 had concentrations larger than 1.5 parts per billion (ppb).

These figures illustrate an apparent chaotic association between amounts of sulfur dioxide emitted by the coal-fired electric utilities and actual observed concentrations at the TRNP-South Unit monitoring site. The apparent chaotic association is due to the range of distances of sources from the Class I area and to space and time variant conditions of the atmosphere during transport, dispersion and depletion of emitted sulfur dioxide that confound pairing the emitted sulfur dioxide with the concentrations.

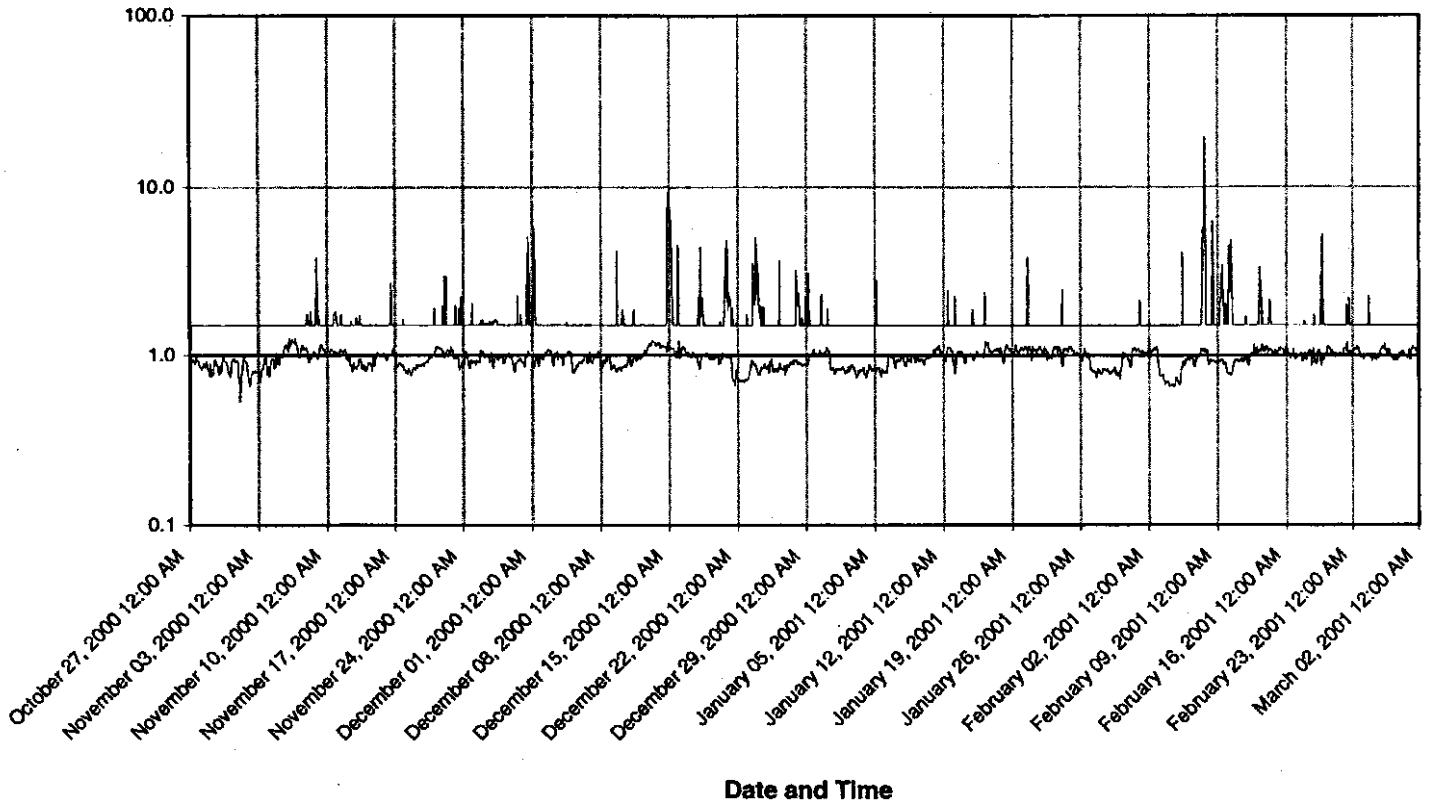

Hourly CEM Sulfur Dioxide Emissions for Years 2000 and 2001
all North Dakota coal-fired electric utilities
(The bar at 38,893 lb/hr is the sum of "actual emissions".)
Sulfur Dioxide (lb / hr)
55,000
50,000
45,000
40,000
35,000
30,000
25,000
20,000
15,000
January 01, 2000 12:00 AM
January 31, 2000 12:00 AM
March 01, 2000 12:00 AM
March 31, 2000 12:00 AM
April 30, 2000 12:00 AM
May 30, 2000 12:00 AM
June 29, 2000 12:00 AM
July 29, 2000 12:00 AM
August 28, 2000 12:00 AM
September 27, 2000 12:00 AM
October 27, 2000 12:00 AM
November 26, 2000 12:00 AM
December 26, 2000 12:00 AM
January 25, 2001 12:00 AM
February 24, 2001 12:00 AM
March 26, 2001 12:00 AM
April 25, 2001 12:00 AM
May 25, 2001 12:00 AM
June 24, 2001 12:00 AM
July 24, 2001 12:00 AM
August 23, 2001 12:00 AM
September 22, 2001 12:00 AM
October 22, 2001 12:00 AM
November 21, 2001 12:00 AM
December 21, 2001 12:00 AM
Date and Time


Hourly CEM Sulfur Dioxide Emissions
for the months of November 2000 through February 2001
all North Dakota coal-fired electric utilities
(The bar at 38,893 lb/hr is the sum of "actual emissions".)
Sulfur Dioxide (lb / hr)
55,000
50,000
45,000
40,000
35,000
30,000
25,000
20,000
15,000
October 27, 2000 12:00 AM
November 03, 2000 12:00 AM
November 10, 2000 12:00 AM
November 17, 2000 12:00 AM
November 24, 2000 12:00 AM
December 01, 2000 12:00 AM
December 08, 2000 12:00 AM
December 15, 2000 12:00 AM
December 22, 2000 12:00 AM
December 29, 2000 12:00 AM
January 05, 2001 12:00 AM
January 12, 2001 12:00 AM
January 19, 2001 12:00 AM
January 26, 2001 12:00 AM
February 02, 2001 12:00 AM
February 09, 2001 12:00 AM
February 16, 2001 12:00 AM
February 23, 2001 12:00 AM
March 02, 2001 12:00 AM
Date and Time

Hourly concentrations (ppb) of sulfur dioxide at TRNP-South Unit (upper plot) and hourly emitted sulfur dioxide divided by actual emissions (lower plot) for years 2000 and 2001.



Hourly concentrations (ppb) of sulfur dioxide at TRNP-South Unit (upper plot) and hourly emitted sulfur dioxide divided by actual emissions (lower plot) for the months of November 2000 through February 2001.



Appendix H – Monitoring data for model accuracy tests.

The State Department of Health has compiled annual air quality monitoring data reports. These reports can be found at the following internet web addresses:

2000 http://www.health.state.nd.us/AQ/ambient/annual/ANN_00.pdf ,
2001 http://www.health.state.nd.us/AQ/ambient/annual/ANN_01.PDF , and
2002 http://www.health.state.nd.us/AQ/ambient/annual/ANN_02.PDF .

Model domain coordinates for monitoring sites

Ambient sulfur dioxide concentrations have been measured with monitors at two PSD Class I areas in western North Dakota. The remaining area of western North Dakota is a PSD Class II area. A monitor station is now located in each of the North and South Units of the TRNP, and two monitors are located east of these Units. The monitor station at the North Unit was operating throughout the years 1990 through 1994 and also after August 2001. The monitor station at the South Unit was operating throughout the years 2000 and later. Monitor stations were operating at rural Dunn Center and rural Hannover throughout the years 1990 through 1994 and 2000 through 2002. The lower detection level of sulfur dioxide monitoring instruments decreased from 2 parts per billion to 1 part per billion (2.6 micrograms per cubic meter) after 1994 and prior to 2000.

A model receptor will be placed at the location of monitors. Model predicted concentrations at these receptors will be used for accuracy tests; these predicted concentrations will not be used for calculation and tabulation of PSD increment exceedances.

Coordinates for locations of sulfur dioxide monitoring sites.					
Monitor location	County	Longitude (degrees)	Latitude (degrees)	Terrain elevation (meters)	Number of nearest Class I area receptor
TRNP – South Unit	Billings	103.3731	46.8928	832	108
TRNP – North Unit	McKenzie	103.2643	47.6018	612	114
rural Dunn Center	Dunn	102.5263	47.3202	683	not applicable
rural Hannover	Oliver	101.4281	47.1858	697	not applicable

Highest 24-hour sulfur dioxide values

Hourly concentration data have been block averaged for each sequential 24-hour block – midnight to midnight Mountain Standard Time, throughout the year for 2000, 2001 and 2002. The 366, or 365, 24-hour averages were then ranked from the highest value to the lowest value. The 40 highest values are provided in attached tables.

The 24-hour concentration data in the attached table reflect the measured consequence of all emitted sulfur dioxide, including any deterioration since PSD baseline more than 23 years earlier. Color shaded data in the table are greater than PSD sulfur dioxide 24-hour increments of 5 ug/m3 and 25 ug/m3, respectively, for PSD Class I and Class II areas. For example, the data indicate that only thirteen of 366 daily concentrations for year 2000 were larger than the 24-hour increment. The sulfur dioxide deterioration cannot exceed these monitored (total) concentrations, and it would equal these monitored concentrations only if there was no background concentration and no sources of sulfur dioxide in the modeling domain at PSD baseline. However, there were many sources at PSD baseline.

Two factors relate to the choice of the number of highest values to include in model accuracy tests.

> The lower useable detection level is 1part per billion for analytical methods that use the hourly sulfur dioxide concentration data, such as 3-hour, 24-hour and annual averaging. However, the lowest useable detection level for other analytical methods that do not average the hourly concentration data is 1.5 parts per billion. [15]
>
> The range of baseline concentrations and range of current concentrations for those changes in concentration that exceed (deterioration as ΔX) an increment are normally not tabulated and reported. These exceedances may not pair with the highest current concentrations.

Thus, model accuracy tests of model predicted concentrations in PSD Class I areas will be confined to use of the 25, or fewer, highest values provided in the attached tables.

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[15] The field instruments for measuring ambient sulfur dioxide are pulsed fluorescence sulfur dioxide analyzers. The instruments are operated in the 60 second averaging time mode. When the instruments are operating in this mode, the zero noise range is 0.5 parts per billion and the lower detection level is 1.0 part per billion. (See operating Instruction Manual P/N 9997 for Model 43C by Thermo Environmental Instruments, Inc., page 1-3.) However, span calibrations of the instruments have been performed at increments of whole number concentrations starting at 2 parts per billion.

A mathematical estimate of baseline concentrations

The second highest 24-hour monitored concentrations in the South Unit of TRNP, which are provided on attached tables, were: for year 2000, 9.39 ug/m3; 2001, 8.81 ug/m3; and 2002, 8.30 ug/m3. Since no monitoring data are available preceding 1980, the 24-hour monitored concentrations for this and other PSD Class I areas at PSD baseline are not known.

Two mathematical methods for determining baseline concentrations are provided in this alternate protocol. Under the first method, which also is the method of prior protocols, the baseline concentration would have been the concentration occurring on the same Julian day of modeled meteorological data, which represents the weather during the baseline year(s). [16] Under the second method, the baseline concentration is the second-highest concentration throughout the year(s) of modeled meteorological data, which also represents the weather during the baseline year(s). If baseline monitoring data were available, deterioration that exceeds the PSD Class I 24-hour sulfur dioxide increment of 5 ug/m3 and that pushes ambient concentrations to the level of the current second highest 24-hour concentration of 9.39 ug/m3 would have had to be begin at a baseline concentration of 4.39 ug/m3 or smaller.

Is a baseline concentration of 4.39 ug/m3 or smaller reasonably feasible? An inventory of emitted sulfur dioxide was assembled for a current period. The ratio of 4.39 ug/m3 and 9.39 ug/m3 is 0.478. The sum of rates of emitted sulfur dioxide for sources at current period is 43,439.2 pounds per hour. A crude guess of emissions during PSD baseline that might have resulted in significant deterioration is the multiplication product of the ratio 0.478 and 43,658.2 pounds per hour, which is 20,868.6 pounds per hour and which is significantly less than the sum of 29,632.7 pounds per hour pursuant to his protocol.

What might have been the baseline concentration? The sum of estimated emission rates during PSD baseline pursuant to this protocol is 67.8 percent of the sum of current rates. These sums do not include the numerous oil and gas production sources; there were about 300 fewer of these sources during the current period. A crude guess of the baseline concentration at the location of the monitor in the South Unit of TRNP can be calculated as the multiplication product of the ratio of 0.678 and the second highest monitored

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[16] When modeling baseline and current emission inventories, the meteorology throughout a modeled year is the same. EPA's current method of determining deterioration in time as well as in space cannot be duplicated with monitoring data. Comparison of monitoring data on a Julian day during current period year(s) to monitoring data on the same Julian day during PSD baseline year(s) as a measure of deterioration presumes that the weather was the same on that day during both time periods. Identical weather on the same Julian day during both time periods is extremely unlikely. If two or more years of baseline monitoring data had been available, how would the data be used in combination with current monitoring data to mathematically determine the deterioration occurring since baseline? One answer is the alternate mathematical method provided by this protocol.

concentration for each current-period year of monitoring data. Thus, a crude guess of baseline concentrations for the Julian day of the second-highest event or for the calender year is: from data for year 2000, 6.37 ug/m3; 2001, 5.97 ug/m3; and 2000, 5.63 ug/m3.

The observation or conclusion emerging from this exercise is that the alternate modeling protocol must be sufficiently robust so as to confidently resolve the amounts of ambient sulfur dioxide deterioration occurring over the 26 years after 19 December 1977, which is the PSD minor source baseline date.

Table of 24-hour averaged sulfur dioxide concentrations at four monitoring locations for years 2000 and 2001.

Year 2000

	PSD Class I areas						PSD Class II area					
	TRNP-NU			TRNP-SU			Dunn Center			Hannover		
Rank	ppb	ug/m3	J. Date	ppb	ug/m3	J. Date	ppb	ug/m3	J. Date	ppb	ug/m3	J. Date
1				3.71	[illegible]	46	7.75	20.31	350	11.58	[illegible]	31
2				3.58	[illegible]	44	7.54	19.76	348	11.17	[illegible]	71
3				2.83	[illegible]	350	6.17	16.16	238	10.50	[illegible]	208
4				2.50	[illegible]	349	4.54	11.90	43	10.21	[illegible]	234
5				2.33	[illegible]	237	4.00	10.48	11	8.29	21.72	260
6		no		2.27	[illegible]	54	3.88	10.15	65	7.96	20.85	195
7				2.21	[illegible]	11	3.88	10.15	349	7.64	20.01	228
8		data		2.17	[illegible]	106	3.71	9.72	184	7.29	19.10	217
9				2.13	[illegible]	43	3.42	8.95	106	7.04	18.45	194
10		for		2.13	[illegible]	238	3.38	8.84	31	6.92	18.12	69
11				2.04	[illegible]	358	3.29	8.62	358	6.33	16.59	43
12		year		2.00	[illegible]	214	3.21	8.41	76	6.13	16.05	147
13				1.96	[illegible]	47	3.17	8.30	247	6.08	15.94	104
14		2000		1.83	4.80	257	3.04	7.97	214	6.08	15.94	237
15				1.79	4.69	355	2.96	7.75	45	5.88	15.39	187
16				1.75	4.59	19	2.88	7.53	244	5.50	14.41	41
17				1.75	4.59	104	2.71	7.10	359	5.38	14.08	161
18				1.75	4.59	331	2.64	6.91	12	5.29	13.86	222
19				1.75	4.59	336	2.42	6.33	15	5.29	13.86	350
20				1.71	4.48	228	2.41	6.31	40	5.04	13.21	202
21				1.63	4.26	15	2.38	6.22	152	4.79	12.55	67
22				1.63	4.26	335	2.38	6.22	228	4.71	12.34	42
23				1.63	4.26	353	2.38	6.22	363	4.71	12.34	97
24				1.58	4.15	164	2.29	6.00	345	4.64	12.15	61
25				1.54	4.04	31	2.21	5.79	5	4.63	12.12	119
26				1.54	4.04	110	2.21	5.79	47	4.58	12.01	171
27				1.54	4.04	190	2.21	5.79	69	4.58	12.01	346
28				1.54	4.04	199	2.17	5.68	46	4.55	11.91	257
29				1.54	4.04	359	2.13	5.57	2	4.50	11.79	66
30				1.50	3.93	313	2.13	5.57	44	4.46	11.68	220
31				1.50	3.93	332	2.09	5.48	320	4.46	11.68	301
32				1.50	3.93	356	2.08	5.46	360	4.46	11.68	334
33				1.50	3.93	363	2.05	5.36	187	4.42	11.57	366
34				1.46	3.82	241	2.04	5.35	74	4.38	11.46	196
35				1.46	3.82	288	2.04	5.35	351	4.33	11.35	351
36				1.42	3.71	126	2.00	5.24	356	4.25	11.14	340
37				1.42	3.71	328	1.96	5.13	19	4.13	10.81	163
38				1.38	3.60	16	1.96	5.13	199	4.09	10.72	201
39				1.38	3.60	71	1.96	5.13	366	4.08	10.70	49
40				1.38	3.60	189	1.92	5.02	49	4.08	10.70	105

Year 2001

	PSD Class I areas						PSD Class II area					
	TRNP-NU			TRNP-SU			Dunn Center			Hannover		
Rank	ppb	ug/m3	J. Date	ppb	ug/m3	J. Date	ppb	ug/m3	J. Date	ppb	ug/m3	J. Date
1	2.38	[redacted]	345	3.96	[redacted]	38	5.21	13.65	45	15.96	[redacted]	24
2	1.92	[redacted]	274	3.36	[redacted]	198	4.77	12.50	190	9.79	[redacted]	84
3	1.71	4.48	362	3.29	[redacted]	219	3.75	9.83	57	9.17	24.02	116
4	1.63	4.26	361	3.21	[redacted]	315	3.21	8.41	42	7.17	18.78	13
5	1.58	4.15	346	2.82	[redacted]	190	3.21	8.41	56	6.88	18.01	145
6	1.54	4.04	310	2.50	[redacted]	316	3.21	8.41	58	6.79	17.79	91
7	1.50	3.93	364	2.21	[redacted]	41	3.17	8.30	44	5.63	14.74	41
8	1.42	3.71	328	2.21	[redacted]	116	3.08	8.08	178	5.58	14.63	81
9	1.38	3.60	258	2.14	[redacted]	339	3.08	8.08	205	5.38	14.08	333
10	1.38	3.60	297	2.08	[redacted]	220	2.96	7.75	195	5.25	13.76	316
11	1.33	3.49	246	2.04	[redacted]	112	2.96	7.75	258	5.17	13.54	154
12	1.25	3.28	365	2.00	[redacted]	338	2.75	7.21	177	5.00	13.10	87
13	1.23	3.22	243	1.92	[redacted]	223	2.58	6.77	220	5.00	13.10	112
14	1.21	3.17	272	1.88	4.91	40	2.54	6.66	50	4.86	12.74	338
15	1.21	3.17	314	1.86	4.88	176	2.50	6.55	109	4.83	12.66	10
16	1.19	3.12	275	1.83	4.80	118	2.46	6.44	32	4.75	12.45	63
17	1.17	3.06	298	1.83	4.80	275	2.33	6.11	41	4.63	12.12	159
18	1.17	3.06	341	1.75	4.59	163	2.25	5.90	38	4.54	11.90	327
19	1.16	3.03	360	1.71	4.48	108	2.25	5.90	64	4.54	11.90	330
20	1.14	2.99	332	1.67	4.37	50	2.25	5.90	310	4.50	11.79	149
21	1.13	2.95	237	1.67	4.37	211	2.21	5.79	15	4.38	11.46	111
22	1.13	2.95	249	1.67	4.37	247	2.21	5.79	55	4.21	11.03	12
23	1.13	2.95	266	1.58	4.15	44	2.17	5.68	31	4.17	10.92	123
24	1.08	2.84	239	1.58	4.15	117	2.17	5.68	43	4.13	10.81	73
25	1.08	2.84	256	1.54	4.04	175	2.17	5.68	247	4.08	10.70	97
26	1.08	2.84	265	1.54	4.04	216	2.13	5.57	11	3.88	10.15	75
27	1.08	2.84	288	1.50	3.93	119	2.13	5.57	112	3.79	9.93	150
28	1.08	2.84	350	1.50	3.93	133	2.08	5.46	2	3.73	9.77	144
29	1.08	2.84	355	1.50	3.93	218	2.04	5.35	46	3.71	9.72	93
30	1.08	2.84	357	1.46	3.82	39	1.96	5.13	49	3.50	9.17	139
31	1.05	2.74	261	1.46	3.82	160	1.96	5.13	346	3.46	9.06	57
32	1.04	2.73	254	1.42	3.71	73	1.92	5.02	148	3.42	8.95	42
33	1.04	2.73	255	1.42	3.71	205	1.92	5.02	224	3.42	8.95	62
34	1.04	2.73	299	1.42	3.71	237	1.83	4.80	219	3.38	8.84	155
35	1.04	2.73	316	1.41	3.69	121	1.83	4.80	345	3.38	8.84	340
36	1.04	2.73	331	1.41	3.69	282	1.78	4.67	24	3.25	8.52	67
37	1.04	2.73	334	1.38	3.60	109	1.75	4.59	20	3.25	8.52	315
38	1.04	2.73	340	1.33	3.49	20	1.75	4.59	39	3.21	8.41	359
39	1.04	2.73	348	1.33	3.49	222	1.75	4.59	48	3.17	8.30	74
40	1.04	2.73	358	1.33	3.49	310	1.75	4.59	260	3.17	8.30	167

Year 2002

PSD Class I areas

Rank	TRNP-NU ppb	TRNP-NU ug/m3	TRNP-NU J. Date	TRNP-SU ppb	TRNP-SU ug/m3	TRNP-SU J. Date
1	3.42	[illegible]	73	4.75	[illegible]	248
2	2.88	[illegible]	66	3.17	[illegible]	297
3	2.42	[illegible]	83	3.04	[illegible]	28
4	2.25	[illegible]	80	2.79	[illegible]	141
5	1.92	[illegible]	39	2.67	[illegible]	283
6	1.92	[illegible]	95	2.63	[illegible]	26
7	1.82	4.76	78	2.46	[illegible]	29
8	1.67	4.37	29	2.38	[illegible]	49
9	1.67	4.37	92	2.38	[illegible]	247
10	1.64	4.29	302	2.25	[illegible]	64
11	1.63	4.26	69	2.21	[illegible]	235
12	1.63	4.26	293	2.17	[illegible]	241
13	1.63	4.26	337	2.17	[illegible]	292
14	1.58	4.15	79	2.08	[illegible]	236
15	1.58	4.15	116	2.08	[illegible]	243
16	1.54	4.04	153	2.08	[illegible]	244
17	1.54	4.04	339	2.08	[illegible]	249
18	1.52	3.99	149	2.08	[illegible]	250
19	1.5	3.93	18	2.04	[illegible]	238
20	1.5	3.93	77	2.00	[illegible]	173
21	1.5	3.93	294	2.00	[illegible]	237
22	1.46	3.83	216	2.00	[illegible]	240
23	1.46	3.82	363	1.96	[illegible]	239
24	1.42	3.71	5	1.96	[illegible]	242
25	1.42	3.71	74	1.96	[illegible]	251
26	1.38	3.60	122	1.95	[illegible]	296
27	1.38	3.60	336	1.92	[illegible]	78
28	1.38	3.6	353	1.83	4.80	234
29	1.38	3.6	357	1.83	4.80	252
30	1.33	3.49	17	1.83	4.80	255
31	1.33	3.49	70	1.79	4.69	246
32	1.33	3.49	81	1.75	4.59	66
33	1.33	3.49	138	1.75	4.59	289
34	1.33	3.49	139	1.75	4.59	290
35	1.29	3.38	11	1.71	4.48	253
36	1.29	3.38	28	1.67	4.37	80
37	1.29	3.38	61	1.67	4.37	82
38	1.29	3.38	75	1.54	4.04	67
39	1.29	3.38	184	1.54	4.04	293
40	1.29	3.38	187	1.50	3.93	27

PSD Class II area

Dunn Center ppb	Dunn Center ug/m3	Dunn Center J. Date	Hannover ppb	Hannover ug/m3	Hannover J. Date
3.46	9.06	26	14.13	[illegible]	205
3.42	8.95	293	9.88	[illegible]	211
3.10	8.11	28	8.19	21.46	70
2.96	7.75	187	7.92	20.74	51
2.79	7.31	66	7.54	19.76	81
2.79	7.31	95	7.00	18.34	49
2.50	6.55	173	6.79	17.79	230
2.46	6.44	83	6.21	16.27	22
2.45	6.43	153	5.92	15.50	82
2.33	6.11	198	5.87	15.38	160
2.29	6.00	234	5.42	14.19	72
2.25	5.90	184	5.25	13.76	136
2.17	5.68	69	5.21	13.65	39
2.13	5.57	73	5.17	13.54	137
2.00	5.24	27	4.96	12.99	95
2.00	5.24	80	4.88	12.77	23
1.96	5.13	294	4.71	12.34	199
1.88	4.91	174	4.63	12.12	158
1.83	4.80	189	4.54	11.90	105
1.79	4.69	39	4.50	11.79	204
1.75	4.59	100	4.00	10.48	358
1.71	4.48	65	3.92	10.26	312
1.71	4.48	68	3.83	10.04	52
1.71	4.48	75	3.71	9.72	79
1.71	4.48	116	3.71	9.72	97
1.71	4.48	336	3.67	9.61	182
1.67	4.37	137	3.67	9.61	296
1.67	4.37	216	3.67	9.61	310
1.67	4.37	248	3.63	9.50	26
1.63	4.26	78	3.54	9.28	300
1.63	4.26	139	3.46	9.06	152
1.58	4.15	81	3.46	9.06	295
1.58	4.15	301	3.38	8.84	206
1.58	4.15	338	3.38	8.84	210
1.54	4.04	122	3.33	8.73	188
1.54	4.04	319	3.25	8.52	126
1.50	3.93	127	3.21	8.41	124
1.50	3.93	152	3.21	8.41	184
1.50	3.93	199	3.21	8.41	365
1.50	3.93	247	3.17	8.30	78

ATTACHMENT 1

Alternative Meteorological Data Sets for North America

Alternative Meteorological Datasets for North America

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18 February 2003

Introduction

In order to provide meteorological inputs to photochemical models for various regulatory purposes and research studies, over the past decade, it has become common practice to use a mesoscale numerical model (most often MM5 and RAMS) to simulate a particular time period. Mostly, these have been run for particular ozone episodes that occurred during particular special study periods (e.g., LMOS, SARMAP, CCOS, TexAQS, etc.). However, recently there has been a desire to reproduce an entire annual cycle of meteorological fields over most of North America. While MM5 has been used to perform these annual simulations, a question can be raised as to whether there are other existing datasets that could be used to provide the necessary meteorological inputs to photochemical models, especially considering the plethora of operational implementations of numerical models that run daily.

This report will examine the possible sources of these alternate datasets. We will evaluate the most likely candidate datasets from several perspectives:

(a) the scientific formulation of the models including a technical appraisal of the formulation of the models and/or analytical procedures that produced the data sets;
(b) the completeness, adequacy, format, and availability of the archives;
(c) the feasibility of supporting the current generation of grid-based air quality models;
(d) recommendations of which datasets might be candidates for multi-variable performance evaluations.

Dataset Requirements

In attempting to identify possible candidate datasets, it is helpful to impose certain minimum requirements to reduce the range of possibilities. Therefore, we will only consider datasets which:

- have a grid resolution less than ½degree (or 60 km)
- are available with a time resolution of at least 6 hours (4 times per day)
- must cover a domain similar to the North America MM5 grid (Figure 1) used in previous and current annual runs

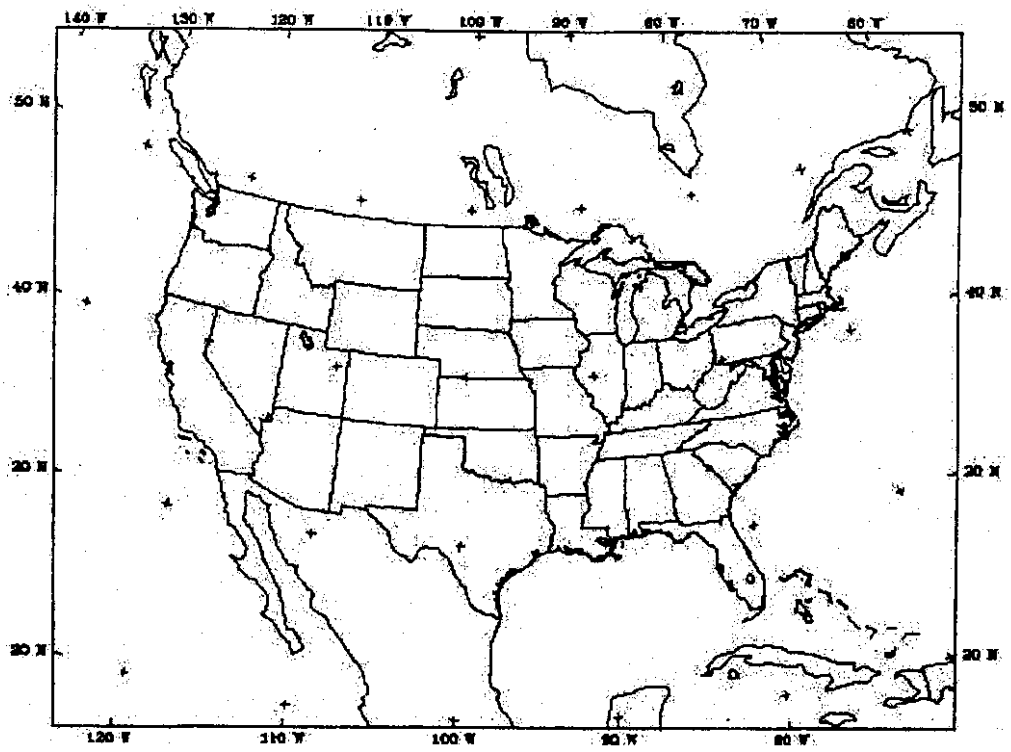


Figure 1: Domain depiction for 36 km grid annual runs

Possible Dataset Sources

Virtually all of the meteorological datasets that are routinely produced and potentially archived are derived from operational forecast cycles. While there are some exceptions, most notably the NCAR/NCEP Reanalysis Data and some ECMWF products, these datasets are global datasets which do not meet the minimum resolution requirements listed above.

Numerous numerical models and analysis software are run operationally daily to produce a range of products from global scale (order 100 km) down to regional scale (order 10 km). These are run by a range of organizations around the world from national government laboratories to universities to private companies. We will focus in this report on the organizations in the US. There are numerous countries and centers that run global models which cover the US, such as CMC (Canadian Meteorological Centre), UKMO (United Kingdom Met Office) (England), ECMWF (European Center for Medium Range Weather Forecasting), JMA (Japan Meteorological Agency), CSIRO (Commonwealth Scientific and Industrial Research Organisation, Australia), CPTEC (Centro de Previsão de Tempo e Estudos Climáticos, Brazil), among others. However, the grid resolutions over North America from these models do not meet the target criteria and access of these data, even if archives exist, can be somewhat problematic and expensive.

Partial list of US organizations producing operational data

- NOAA/NWS/NCEP – main national forecast center in the US running various forecast and analysis models – ETA, MRF (produces AVN forecasts), RUC
- Other US government labs
  - NOAA Air Resources Laboratory (ARL)
  - NOAA Forecast Systems Laboratory (FSL)
  - Various Department of Energy (DOE) labs
  - National Center for Atmospheric Research (NCAR)
- Department of Defense
  - Air Force Weather Agency (AFWA)
  - Fleet Numerical Meteorology and Oceanography Center (FNMOC)
  - Defense Threat Reduction Agency (DTRA)
  - Individual bases – Dugway Air Force Base, etc.
- Universities
  - Colorado State University
  - Penn State University
  - University of Utah
  - University of Oklahoma
  - Florida State University
  - University of Wisconsin
- Private companies
  - Meso, Inc.
  - ForesightWX
  - ATMET
  - Mission Research Corporation
  - Weather Central
  - DoD contractors – TASC, PRC, etc.

The majority of these organizations either focus on their own individual needs, or the needs of their client base. Very few of these groups actually produce higher resolution analyses and forecasts for all of CONUS and North America. From the above list, following are the list of groups that produce at least daily forecasts or analyses at adequate resolution for the continent:

- ForesightWX – produces 10 km resolution over CONUS 4 times per day, hourly forecasts with MM5

- Weather Central – uses a derivative of RAMS (University of Wisconsin - NMS model) to produce 20 km CONUS forecasts. Focuses primarily on TV weather, distributes graphics and limited data.

- AFWA – MM5 forecasts over CONUS, resolution location of nests vary depending on political situation

- FNMOC – COAMPS (http://www.fnoc.navy.mil/PUBLIC/MODEL_REPORTS/MODEL_SPEC/coamps2.0.html) forecasts, nested grids of 81-27-9 km, focuses on ocean and coastal regions so non-contiguous window across CONUS

- FSL – operationally produces a 40km RUC run as a backup for NCEP, along with numerous other short-term experimental runs

- NCEP – multiple products (RUC, ETA, MRF, others), now tasked with operational distribution

The private companies, ForesightWX and Weather Central, will not be considered further, as archives of their products do not exist, and they normally do not distribute full numerical data in real-time.

The military organizations (AFWA and FNMOC) are stronger possibilities. However, there are some difficulties. Our experience has been that a government to government MOU would have to be created between EPA and DoD in order for EPA to have access to the data. These are usually rather time-consuming and expensive. In addition, EPA would most likely need to take on the additional expense of installing and maintaining a data distribution system at those sites in order to access the data. Other disadvantages:

- FNMOC
  - non-contiguous domain for CONUS
  - COAMPS is a newer model that does not have track record; forecasts only begun within past 3 years
  - Domain structure and locations have been dependent on political/military situation
- AFWA
  - Domain structure and locations have been dependent on political/military situation
  - Real-time CONUS MM5 forecasts serve as backup to NCEP and are available on NCEP's operational site

FSL's backup RUC is also available on NCEP's operational FTP site. Therefore, consistent with the expectations stated in the RFP for this project, this leaves the NCEP products as the only reasonable alternatives to rerunning a mesoscale model for the annual runs. We will further breakdown the ETA and RUC models, summarize their features, and products below as to what is available in archives versus real-time access.

NCEP Models

RUC description

The Regional Analysis and Prediction branch of NOAA/FSL in Boulder originally developed the Mesoscale Analysis and Prediction System (MAPS) back in the 1980's which was renamed the Rapid Update Cycle (RUC) upon installation at NCEP. RUC/MAPS is primarily a data analysis package, although it contains a prediction component which is used to provide the first-guess fields.

The key features of RUC/MAPS include:

- high-frequency (every 1h) 3-d objective analyses over the contiguous United States
- high-frequency (every 1h) short-range weather model forecasts (out to 12 h) in support of aviation and other mesoscale weather forecast users
- assimilation of data from:
    - commercial aircraft (relayed through ACARS - Aircraft Communications, Addressing, and Reporting System)
    - wind profilers (404 and boundary-layer 915 MHz)
    - rawinsondes and special dropwinsondes
    - surface reporting stations and buoys
    - RASS (Radio Acoustic Sounding System) - experimental
    - VAD (velocity-azimuth display) winds from NWS WSR-88D radars
    - GOES total precipitable water estimates
    - SSM/I total precipitable water estimates
    - GPS total precipitable water estimates
    - GOES high-density visible and IR cloud drift winds
- a hybrid isentropic-sigma vertical coordinate

The current RUC runs on a 20 km grid and is available on this native grid. Before April 2002, RUC was run on a 40 km grid at NCEP.

ETA description

ETA is a mesoscale model originally developed by Fedor Mesinger and Zavisa Janjic in Yugoslavia and NMC in the late 1980's and early 1990's. The basic new feature in the ETA model was the topography "step" coordinate, which used the Greek letter "eta" in the technical description. The grid structure is a Cartesian-type grid where the coordinate levels are horizontal, rather than a terrain-following coordinate. Other features include (circa October, 2000):

- Grid: Semi-staggered Arakawa E-grid

- Horizontal Resolution: 12 km
- Vertical levels: 38
- Topography: Silhouette step topography
- Model Dynamics: (Black, 1994; Weather & Forecasting)
  - Fundamental prognostic variables – T, u, v, q, Ps, TKE, cloud water/ice
  - Inertial gravity wave adjustment – forward-backward scheme
  - Vertical advection
    - Euler-backward scheme
    - centered in space
    - piecewise linear for q
  - Horizontal advection
    - modified Euler-backward scheme
    - Janjic advection in space
    - Conservative, (nearly) shape-preserving scheme for H_2O
    - Upstream advection near boundaries
- Model Physics: (Janjic, 1994; Mon. Wea. Rev.)
  - Betts-Miller-Janjic convection
  - Mellor-Yamada level 2.5 turbulent exchange
  - GFDL Radiation
  - Explicit cloud water/ice prediction
  - 4 layer soil scheme with vegetation
  - Δ^2 horizontal diffusion
- Initial and Lateral boundary conditions: One way interaction
  - NCMRWF global analysis and 6 hourly global model forecasts
- Time-dependent surface fields:
  - SST, snowdepth

There has been and continues to be a significant distinction between the grid the native ETA grid and the grids that are available both in the archives and operationally. This will be addressed in the next sections.

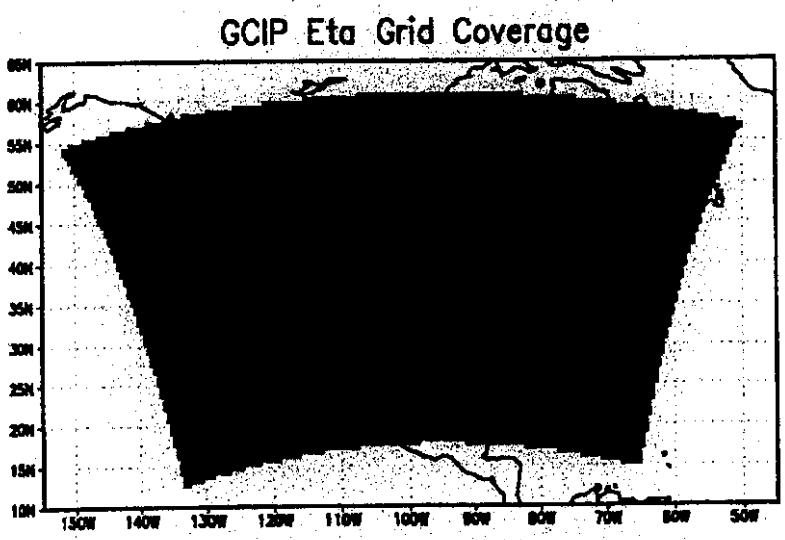
ETA and RUC Archived Data

While there are tens of gigabytes of data produced from ETA and RUC operationally by NCEP daily, a rather surprisingly small amount of this data is archived in any form. There are numerous unofficial archives maintained by individual groups. For example, at ATMET, we have maintained an archive of the 00 UTC ETA and AVN forecasts for most of the past 2 years from our own operational cycles. But given that this provides only one actual EDAS analysis per day, it would be inappropriate to use directly for photochemical modeling applications.

For the "official" archives, there is only one location that has any data routinely available. NCAR has maintained an archive for the GCIP (the Global Energy and Water Cycle Experiment (GEWEX) Continental-Scale International Project). It was launched in the Mississippi River basin to take advantage of the extensive existing meteorological and

hydrological networks with the primary goal: to demonstrate skill in predicting changes in water resources on time scales up to seasonal and annual as an integral part of the climate system. GCIP was fully implemented in 1995 and phased out in 2001.However, a follow-on project call GAPP (GEWEX Americas Prediction Project) has begun, which hopefully will maintain the funding for the continuation of these archives.

NCAR has maintained the ETA archives for the periods 1 May 1995 - 27 Sep 1999 and 19 Nov 1999 – present. The dataset contains the EDAS analysis fields (3 hourly), the ETA initialization fields (3 hourly), and the ETA forecast fields (6 hourly). The 3-D atmospheric field is defined on 25 mb levels from 100-850 mb, then 50 mb from 800-50 mb. The horizontal grid is a 40 km Lambert-Conformal grid (NCEP grid designation 212). Note in the time period of this archive, ETA was actually run on various resolutions between 32 km and 12 km on a polar-stereographic projection. A depiction of the 40 km grid is shown below.



This archive has been used to provide the initial and boundary conditions for meteorological model (RAMS and MM5) runs which provide input to photochemical models. While even the 40 km resolution is similar to the 36 km MM5 resolution used for the annual runs, there are some limitations to using this dataset directly for photochemical inputs:

- 3 hourly time resolution – given the rather coarse spatial resolution, this is probably not a significant factor to the accuracy of the photochemical models, but it is less than the 1 hour resolution usually used. The meteorological preprocessor or photochemical model would have to account more carefully for various fields such as shortwave radiation.
- Lack of information for vertical diffusivity – the archive files do not contain TKE or vertical diffusivity. The Kv fields would have to be parameterized according to deformation-based or other schemes.

- Lack of vertical motion – only the 700 mb vertical motion is available in the EDAS files.
- Lack of cloud information – only specific humidity is reported in the EDAS files. It is unlikely that it is allowed to be larger than vapor saturation.

NCAR also has maintained an archive of the RUC fields for the GCIP project. Unfortunately, they have only kept a very limited subset of data from FSL's 40 km runs. This subset only includes a few pressure levels and variables (winds/heights at 250, 500, 850, and 1000 mb; temperature/humidity at 850 mb), along with a few things defined at the surface. Overall, the archive is not useful as input into photochemical models or as first-guess fields for meteorological models.

NCEP real-time datasets

As mentioned, there is an impressive array of datasets that are available in real time from the NCEP public FTP site. Here is just a sampling and some of the characteristics:

- ETA – numerous grids, including 12 km analysis and forecast fields which include TKE and vertical motion. Analyses and forecast runs are started every 6 hours and forecasts are available every 3 hours out to 84 hours.
- RUC – 20/40 km grids with data analyses available every hour
- MM5 – AFWA backup runs covering CONUS at 45 km. Analyses and forecast runs are started every 6 hours and forecasts are available every 3 hours out to 48 hours.
- Global observations – includes hourly surface observations

The RUC operational data is by far the most complete dataset available in lieu of running a mesoscale model. Following are the characteristics of the current RUC operational data available at NCEP:

- 20 and 40 km Lambert-Conformal grids
- Data analyses are performed every hour
- At the 3 hourly data times (00,03,06,09,12,15,18,21Z), the analysis fields and the 1,2,3,6,9,12 hour forecast fields are available.
- At the other data times, the analysis field and the 1,2,3 hour forecast fields are available.
- Each analysis or forecast field is available both on pressure levels or on the native RUC hybrid sigma/isentropic grid.
- The pressure level datasets have 25 mb resolution from 1000 to 100 mb. These datasets have the following variables: u, v, temperature, height, relative humidity, and vertical motion.
- The hybrid coordinate datasets have 50 levels and have the following variables: u, v, pressure, height, virtual potential temperature, vertical motion, water vapor mixing ratio, cloud water mixing ratio, rain water mixing ratio, ice/snow/graupel mixing ratios, and TKE.

- Both the pressure and hybrid datasets contain numerous surface fields, such as wind at 10m, temperature at 2m, soil temperature and moisture at 6 levels, precipitation, and snow depth.

Recommendations

Based upon the review we performed for this report and our past experiences working with these datasets, we have the following conclusions and recommendations:

- *No existing archive is adequate to provide an alternative to the annual runs for past time years.* The NCAR ETA GCIP archives are the closest possibility but there are limitations.
- *EPA should consider setting up or contracting the creation and maintenance of a real-time observation and gridded data archive system.* There is a significant amount of good quality data available in real-time including full global observations and the RUC 20 km gridded analyses. No organization currently is responsible for maintaining an archive. For future years, where it can be reasonably expected that that the same level of air quality simulations will be performed, starting an archive now could provide significant performance and cost benefits in the future. Also, since the GCIP project has been phased out, it is unclear how long NCAR will be funded to maintain even the current level of RUC and ETA archives.
- *Based upon scientific formulation, the real-time RUC datasets should be strongly considered for performance evaluation.* Along with possible use as a future replacement for annual runs, the use of the RUC datasets for FDDA in models such as MM5 and RAMS could significantly improve model performance over using the coarser resolution datasets such as the current ETA and Reanalysis datasets.
- *Direct verification of ETA and Reanalysis datasets should be considered.* These datasets are routinely used in the current methodologies as first-guess fields for the initialization and FDDA in the meteorological models used for air quality. Aside from a few cases where equivalent MM5 runs were performed using one or the other of these datasets, there has been no direct evaluation to our knowledge.

References

Following are various links to some of the organizations and models mentioned above.

International organizations

CMC (Canadian Meteorological Centre)
http://www.msc-smc.ec.gc.ca/cmc/index_e.html

UKMO (United Kingdom Met Office)
http://www.metoffice.gov.uk/

ECMWF (European Center for Medium Range Weather Forecasting),
http://www.ecmwf.int/

JMA (Japan Meteorological Agency)
http://www.jma.go.jp/JMA_HP/jma/indexe.html

CSIRO (Commonwealth Scientific and Industrial Research Organisation, Australia)
http://www.csiro.au/

CPTEC (Centro de Previsão de Tempo e Estudos Climáticos, Brazil)
http://www.cptec.inpe.br/

US Organizations

NOAA/NWS/NCEP
http://www.ncep.noaa.gov/

NOAA Air Resources Laboratory (ARL)
http://www.arl.noaa.gov/

NOAA Forecast Systems Laboratory (FSL)
http://www.fsl.noaa.gov/

National Center for Atmospheric Research (NCAR)
http://www.ncar.ucar.edu/ncar/

Air Force Weather Agency (AFWA)
https://afweather.afwa.af.mil/

Fleet Numerical Meteorology and Oceanography Center (FNMOC)
http://www.fnoc.navy.mil/

Defense Threat Reduction Agency (DTRA)
http://www.dtra.mil/

Models and analysis software

RAMS
http://www.atmet.com/

http://rams.atmos.colostate.edu/

MM5
http://www.mmm.ucar.edu/mm5/mm5-home.html

COAMPS
http://www.fnoc.navy.mil/PUBLIC/MODEL_REPORTS/MODEL_SPEC/coamps2.0.html

RUC
http://maps.fsl.noaa.gov/

ETA and MRF (now GFS)
http://www.emc.ncep.noaa.gov/modelinfo/

ATTACHMENT 2

The Preparation of NOAA RUC-2 Data for Ingest by CALMET as MM5 Prognostic Mesoscale Meteorological Data. [1]

[1] The attachment was included with other material provided by ENSR Corporation in March 2003 in explanation of RUC-2 derived input for the CALMET model.

Meteorological Data Preparation for ENSR Calmet Study

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General Approach:

About Meteorological Modeling
Prognostic (predictive) models are well known to have significant advantages over diagnostic windfield models. Dynamic constraints are those resulting from the application of conservation laws involving time derivatives, such as conservation of momentum. The chief drawback of prognostic models is the computational expense of running them. Computational stability considerations require that the models be stepped forward with a time-step that is proportional to the grid cell size. Thus, high-resolution grids require an extremely large number of time-steps to be computed in order to cover the needs of a long-term air quality study. For this reason, high-resolution prognostic models are most often applied to episodic case studies.

While the application of customized prognostic meteorological models to long-term air quality studies can in some cases be prohibitively expensive, data from NOAA prognostic model outputs and analyses can be combined with mesoscale data assimilation systems to produce high-resolution data sets of long duration. NOAA runs a suite of models at varying initial times, resolutions, domains of coverage, and forecast duration. Each model run starts with results from a previous run, combined with all available observed data, including surface and upper air observations, satellite, and radar data. This process of combining the various data sources to yield a unified representation of the three-dimensional atmosphere is termed assimilation.

Assimilation has been an area of active research over the years. As increasingly accurate analyses become available, combining more data types is one of the principal means for improving forecast quality. Our process for CALMET/CALPUFF studies reaps the benefits of this research by basing the production of our "digital atmosphere" on these NOAA analyses.

We use our exclusive archive of NOAA's RUC2 model data to initialize the CALMET model. RUC, or Rapid Update Cycle, is a short-term forecast model that is re-initialized each hour based on previous model results and actual meteorological readings. Using it's NOAAport satellite receiver system,

SSESCO has been archiving these RUC2 analyses for over three years in order to apply the "real world" data to future air quality studies. The RUC model grid contains 40 km cells, with over 40 layers of data in the vertical dimension. This resolution is sufficient to easily represent the upper air features captured by the radiosonde network.

Resolution Considerations
One drawback in applying the RUC2 data directly to air quality studies is that a 40 km grid is typically not of high enough resolution to capture all of the relevant flow and thermal structures that arise near the earth's surface. To avoid this problem, we utilize a technique to introduce high-resolution terrain data and surface observations using a "mesoscale assimilation system".

Data Assimilation
While NOAA has been advancing the assimilation and modeling process as applied to synoptic scale weather systems, a parallel effort in mesoscale modeling systems has been proceeding at a number of governmental and educational research institutions. Foremost among those efforts has been the work done at the Center for the Analysis and Predictions of Storms (CAPS), at the University of Oklahoma. This group, funded by NSF and the FAA, is focused on research and the development of software tools related to small-scale weather phenomenon. We have chosen the ARPS Data Assimilation System (ADAS), for use as a mesoscale assimilation tool.

We apply the ADAS system by starting with a "first-guess" field derived from the archives of NOAA model data and then factor in observational meteorological data and performing climatalogical, spatial, and temporal continuity checking on the data. The key to the assimilation process is the blending of different data sources, each with their own error characteristics into a unified, "most probable" three-dimensional distribution of the target variable.

Data Analysis and Preparation for CALMET Modeling
Taking into account the error characteristics of the first-guess gridded data and each of the observational sources, an objective analysis onto the target CALMET model grid is performed by employing a highly efficient iterative approach to the widely used Statistical or Optimal Interpolation (OI) technique, known as the Bratseth technique. Mass conservation and boundary conditions are then applied to derive the vertical motion fields.

For each hour in a study, we performs an analysis using the RUC analyses for a first guess field and combine it with the metar surface observations. The RUC gridded analyses already capture the upper air information from the radiosondes, in addition to numerous other data sources used in the NOAA assimilation process such as.

- Commercial Aircraft through the ACARSW system
- Wind Profilers (404 and Boundary Layer 915 Mhz)

- Rawinsondes and dropwindsondes
- Surface stations and buoys
- VAD winds from WSR-88D nexrad radars
- GOES total precipitable water estimates
- SSM/I total precipitable water estimates
- GPS total precipitable water estimates
- GOES high-density visible and IR cloud drift winds

Many of the upper air resources, such as the aircraft, nexrad, profiler, and satellite derived information have much finer time resolution than the Radiosondes, whose 12 hour time spacing greatly reduces their usefulness.

The mesoscale assimilation of the surface data recaptures the high-resolution information lost in the 40 km grid, and to allows us re-compute mass conservation in the presence of terrain resolved at the higher CALMET resolution. Temperature, pressure, wind, and humidity fields are computed using the Bratseth implementation of the Optimal Interpolation algorithm.

The datasets developed by this process can be viewed in 3D and verified over the time period of the study using SSESCO's EWB software package. Then, the resulting data are input into CALMET through its MM5 ingest capability. In addition, metar reports of fractional cloud coverage are analyzed to create a gridded cloud coverage field. The various output fields are then written in the "MM5.dat" format accepted by CALMET.

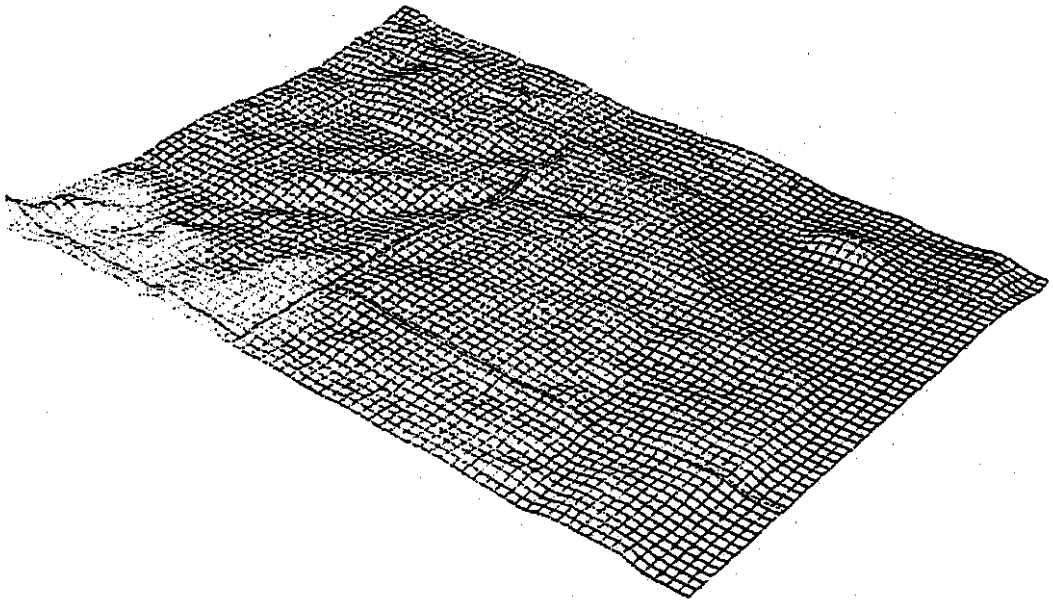
The data is input into Calmet in the following ways:

- As first guess data in the form of the MM5.DAT file
- In the form of a set of surface observations (a SURF.DAT file) derived from a subset of the assimilation grid points. This is to ensure that Calmet interpolates an accurate temperature field for the lowest model level.
- In the form of a set of upper air observations files (UP1.DAT, UP2.DAT, etc.) derived from a sub-sample of the assimilation grid. These ensure that Calmet benefits from the three dimensional temperature fields formed in the assimilation process. More specifically, for purposes of calculating the evolution of the mixing height, Calmet takes a measure of the background potential temperature lapse rate at the top of the PBL from a nearby sounding. By including a dense set of upper air files, the model sees the lapse rate information at much higher time and space resolution than one normally would get from widely spaced balloon sounds that are 12 hours apart.

Case Specifics:

Assimilation grid configuration:

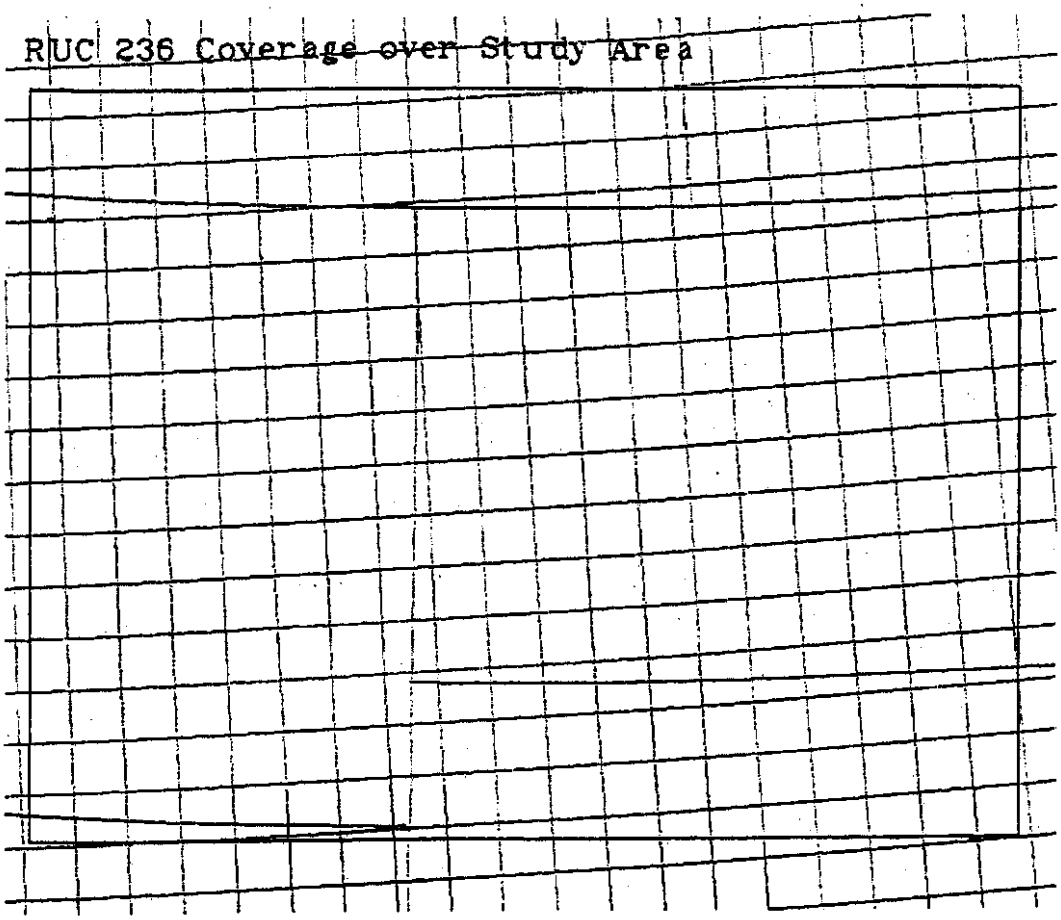
A ten km Lambert Conformal grid was used, with 73 cells in the W-E (X) direction and 56 cells in the S-N (Y) direction. The grid center was at 103 deg W and 47.35 deg N.



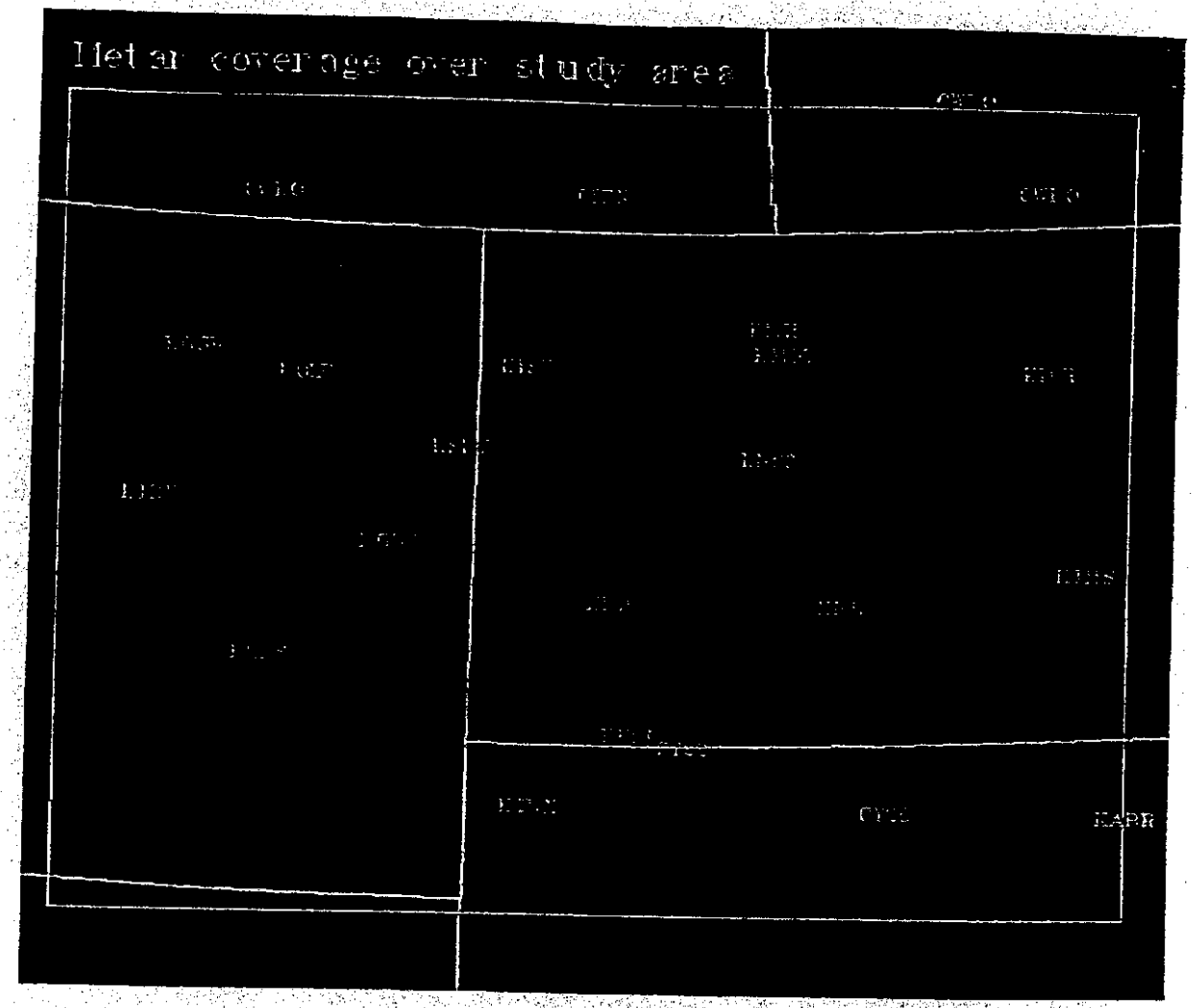
Input data sources:

Hourly RUC analyses were applied for the year 2000. The vast majority of the hours (96.5%) used data from the NOAA 236 grid, a 40 km Lambert grid. While the remaining hours used the 211 grid, an 80 km Lambert grid. The RUC data includes data on 37 pressure levels from 1000 to 100mb in 25 mb increments, as well as a set of surface level data. In some instances the grib file was missing for a particular hour. In that case the first gues for the assimilation was time interpolated from the neighboring time frames.

The following image shows the RUC 236 coverage over the study area:

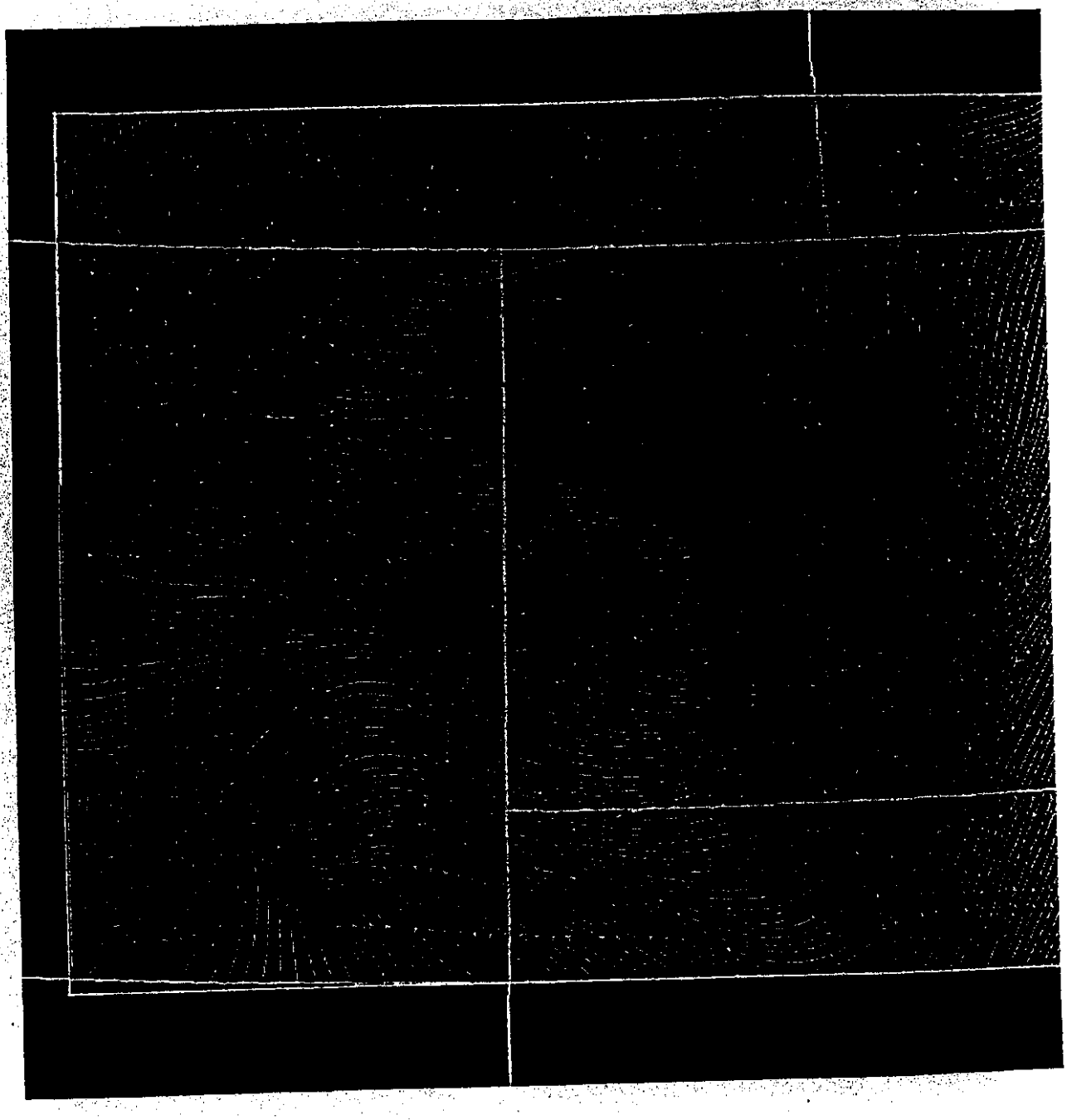


Surface data input consisted of 22 metar stations within the study domain, although all stations might not be reporting for a particular hour.

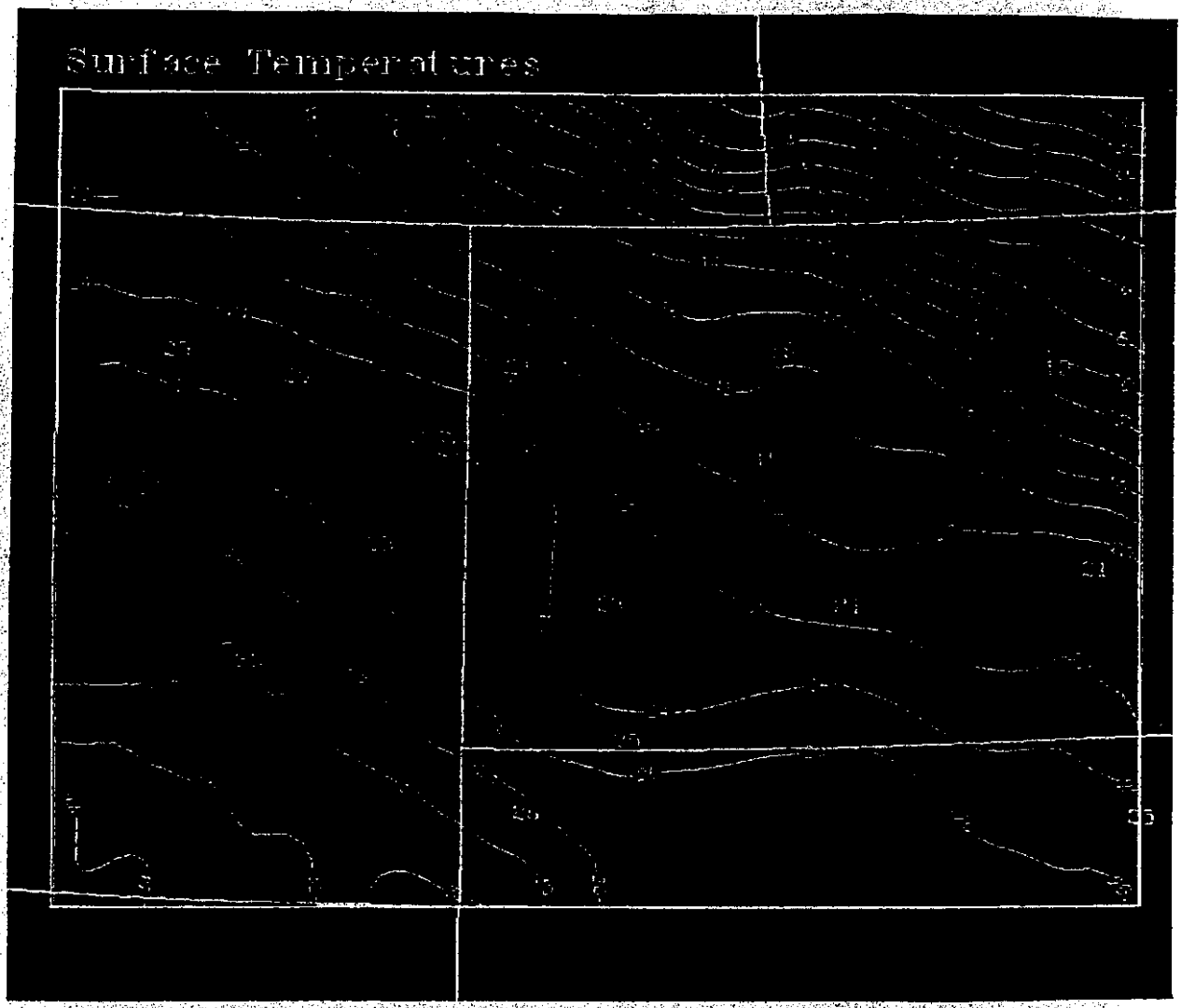


Data quality control for the metar observations was performed in three ways. Observations were compared against reasonable bounds by the assimilation program. Observations were compared against interpolations of neighboring stations by the assimilation program. Finally, the assimilation outputs were visually inspected by a meteorologist using the EWB analysis/visualization software. Any bad observations were flagged and removed from the analysis.

Streamline analysis of the assimilation output:



Temperature contours from the assimilation:



Calmet inputs:

An MM5.DAT file was produced for all hours of the year 2000. In addition, a SURF.DAT file was produced for each hour, containing 192 samples from the assimilation grid. Upper air input files were produced at 42 sites from the assimilation grid, again for all hours of the year.